REPORT SD-TR-85-76

AD-A162 479

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Communication Satellites
1958 to 1986

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1 October 1984

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Interim Report

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Prepared for

SPACE DIVISION
AIR FORCE SYSTEMS COMMAND
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This interim report was submitted by The Aerospace Corporation, El Segundo, CA 90245, under Contract F04701-83-C-0084 with the Space Division (AFSC), Los Angeles Air Force Station, P. O. Box 92960, Worldway Postal Center, Los Angeles, CA 90009-2960. It was reviewed and approved for The Aerospace Corporation by H. E. McDonnell, Programs Group. Col. L. C. Young, SD/TAX was the project engineer for Space Communications Systems.

This report has been reviewed by the Office of Information (OIS) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: SD-TR-85-76
2. GOVT ACCESSION NO.: AD-A162479
3. RECIPIENT'S CATALOG NUMBER:

4. TITLE (and Subtitle): COMMUNICATION SATELLITES 1958 to 1986
5. TYPE OF REPORT & PERIOD COVERED: Interim
6. PERFORMING ORG. REPORT NUMBER: TR-0084A(5417-03)-1

7. AUTHOR(s): Donald H. Martin
8. CONTRACT OR GRANT NUMBER(s): F04701-83-C-0084

9. PERFORMING ORGANIZATION NAME AND ADDRESS: The Aerospace Corporation, El Segundo, CA. 90245
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS:

11. CONTROLLING OFFICE NAME AND ADDRESS: Space Division/AFSC, Los Angeles Air Force Station, P.O. Box 92960, Worldway Postal Center, Los Angeles, CA. 90009-2960
12. REPORT DATE: 1 October 1984
13. NUMBER OF PAGES: 649

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):
15. SECURITY CLASS. (of this report): Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

(20) → Report includes

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Military Communication Satellites,
Commercial Communication Satellites,
Experimental Communication Satellites, and
Communication Satellite History, fy

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report provides a description of each type of communication satellite that has been launched or will be launched by 1986. The development, purpose, and basic characteristics of each type of satellite are discussed, a picture of the satellite and a block diagram of its communication subsystem are presented, and various technical details and significant dates are tabulated. In addition to basic satellite properties such as size, weight, design life, and orbit, the descriptions include communications parameters such as operating frequencies

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19. KEY WORDS (Continued)

20. ABSTRACT (Continued)

and channelization; transmitter power; receiver noise figure; and antenna sizes, beamwidths, and gains. In selected cases, the satellite description is supplemented with information on system operations and ground terminals. Extensive references to the open literature, upon which the descriptions are based, and a bibliography are included in the report.

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PREFACE

This report provides a description of each type of communication satellite that has been launched or will be launched by 1986. Some currently proposed satellites that may be implemented after 1986 are mentioned in brief. All information herein is based on references that were available by 12 September 1983, except that satellite launch dates through June 1984 were added during proofreading.

This report supersedes The Aerospace Corporation TR-0077(2790-01)-1, Communication Satellites, 1958 to 1980, dated 1 February 1977 (SAMSO-TR-77-76), and TR-0079(4417-01)-1, Communication Satellites, 1958 to 1982, dated 10 September 1979 (SAMSO-TR-79-078).

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1. INTRODUCTION

Communication satellites represent one of the most significant applications of space technology. Communication satellite experiments began early in the space age and, since 1965, satellites have been employed in operational communications systems. One indication of the growth of this field is that a new type of commmunication satellite has been or will be launched every year except one from 1965 to 1986. The usefulness of communication satellites is emphasized by operational applications internationally, involving about 110 countries, and domestically, in over 25 countries, for communication services of all types to both large and small terminals on land and on ships. Furthermore, while some of these systems are government sponsored, others are commercial ventures that in some cases are in competition with the terrestrial communications industry.

The purpose of this report is to describe and summarize the technical details of each type of communication satellite for the years 1958 to 1986. An overview of the satellites covered by this report is given in Figure 1-1. For each satellite type, the corresponding time line extends from the first launch to the end of the operation of that type. Following a brief historical survey, the five major sections of this report each covers one of the groups indicated in Figure 1-1. Within each section, the satellite types are ordered chronologically according to their initial launch dates. With the description of each satellite is a picture or drawing of it, a block diagram of its communication subsystem, and a tabular summary of details.* Somewhat less material is presented for a few of the earliest satellites and also for those satellites whose designs are yet to be completed.

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*Values in these tables may differ from those in other documents because of the variations in definitions of the parameters (e.g., maximum vs nominal), which are not always stated. Differences also arise from the source of the value (design vs measurement) and the time point (i.e., prelaunch, beginning of life, end of life). Where possible, these qualifying factors are stated.

This report includes all types of communication satellites that have been launched as well as those in development and planning that are relatively certain to be launched. Past studies that did not result in a launch and current proposals that are unlikely to be implemented by 1986 are not described in detail, but in some cases are mentioned in relation to more definitive programs. While the primary purpose of this report is to describe communication satellites, each satellite is only a part of a larger communication system. Therefore, for some systems, material on the earth terminals and satellite operations is presented with the satellite description.

The final section of this report briefly discusses likely communication satellite technology and applications of the late 1980s to early 1990s. Appendix A gives a list of symbols common to the communication subsystem block diagrams presented throughout the report. Appendix B is a glossary of abbreviations and acronyms used in the report. Appendix C presents a variety of information on international frequency allocations applicable to communication satellites. Appendix D describes the various telemetry, tracking, and command subsystems currently used by communication satellites. Appendix E discusses the use of satellite beacons for atmospheric research, especially in characterizing the atmosphere as a communications channel.

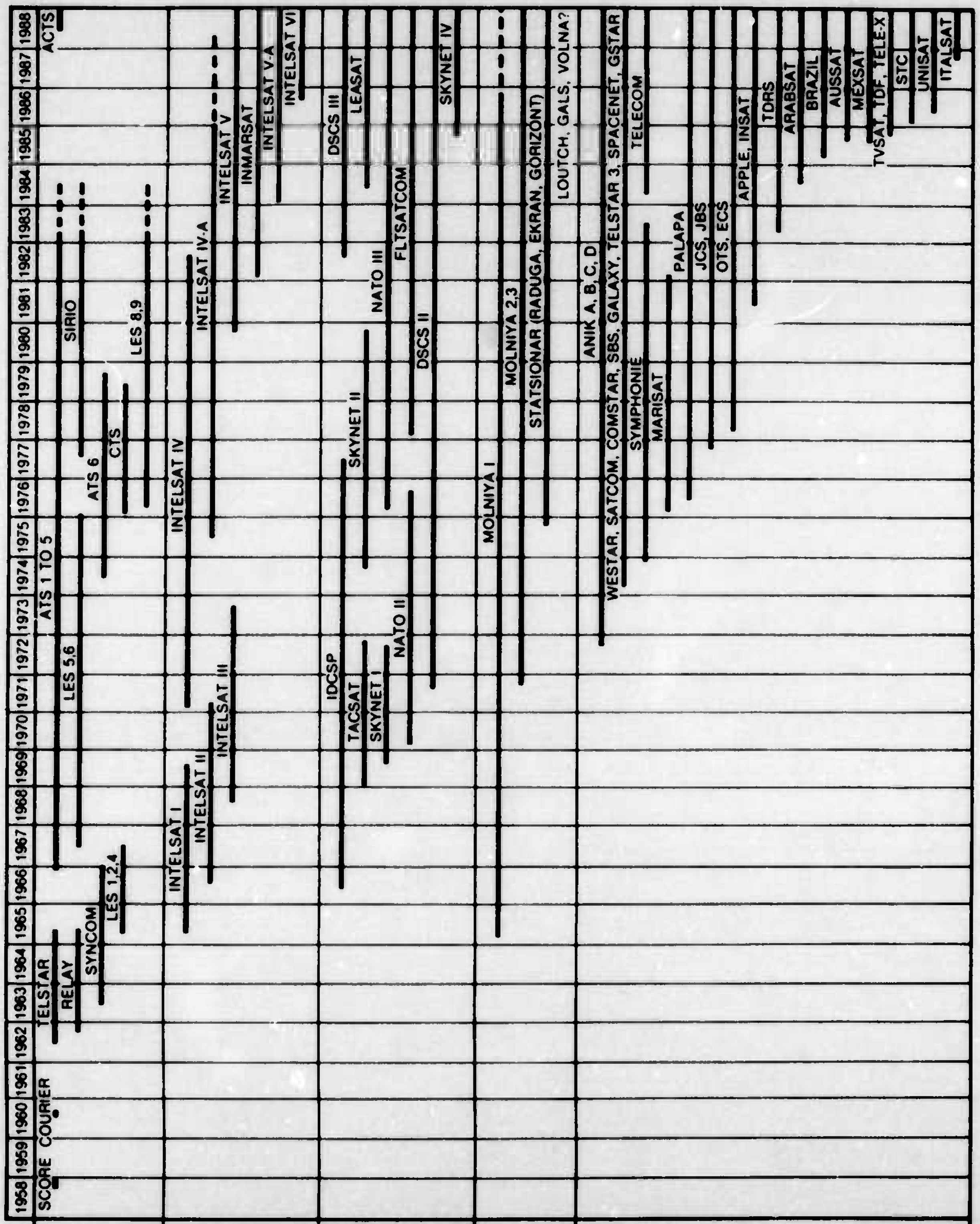

Figure 1-1. Communication Satellite Programs

2. HISTORICAL BACKGROUND*

The first well-known article on communication satellites was written in 1945. The article discusses the synchronous orbit and the global coverage possible with three satellites in this orbit. Some other subjects mentioned are earth coverage and spot beam antennas, multiple beam antennas, optical and radio crosslinks between the satellites, and solar arrays for a prime power source. A rough calculation is given for a 4-GHz downlink, concluding that 10 W of power is sufficient for a voice link with a three-ft transmitting antenna and one-ft receiving antenna.

The next article on this subject was written in 1955. However, the first space communications activity can be traced back to 1946 when the Army achieved radar contact with the moon. In 1954 the Navy began communications experiments using the moon as a passive reflector. By 1959 an operational communication link was established between Hawaii and Washington, D.C. This link was available four to ten hours per day until 1963 when the program was stopped, apparently because of the progress in artificial, active communication satellites.

The first man-made communication satellite, Project SCORE, was launched in December 1958. Its operating life was limited to 12 days when the batteries failed. By 1959 the technical journals began to print many articles on communication satellite topics. Typical subjects of discussion were the merits of passive vs active satellites, low vs synchronous altitude, and random orbital positions vs stationkeeping. In 1960 two journals devoted special issues to space electronics with a total of more than ten articles on communications satellites. In 1962 to 1964 the medium altitude Telstar and Relay programs and the synchronous altitude Syncom program proved the analytical predictions about satellite communications and provided many convincing demonstrations. These programs led to the beginning of operational

*Refs. 1-8.

satellite communications in 1965 as well as to a continuing experimental effort that is still advancing the state of the art.

3. EXPERIMENTAL SATELLITES

Although the performance of communication satellites could be predicted theoretically, until 1962 or 1963 there existed considerable doubt as to whether their actual performance would match the theory. This was one of the basic motivations for the early communication satellite experiments. Two other important factors were the desire to prove the satellite hardware (since space technology in general was still in its infancy) and the need to test operational procedures and ground equipment. While the first few experiments (SCORE, Courier, and Echo) were very brief beginnings, the Telstar, Relay, and Syncom satellites laid definite foundations for the first operational satellites.

Communication satellites have been in operational commercial and military service since 1965 and 1967, respectively. However, there was, and still is, the need for additional experimental satellites. These are used to prove new technologies for later introduction into operational satellites. The satellites that are strictly experimental are described in this section of the report. Other satellites, which have combined experimental and operational objectives, are discussed in other sections. Examples of the latter are the Japanese and European programs (Section 7).

3.1 SCORE (Refs. 9-12)

The first artificial communication satellite, called Project SCORE (Signal Communication by Orbiting Relay Equipment), was launched in December 1958. The primary purpose of the project was to demonstrate that an Atlas missile could be put into orbit. Demonstration of a communications repeater was the secondary goal.

The entire communication subsystem was developed in six months by modifying commercial equipment. Two redundant sets of equipment were mounted in the nose of the missile. Four antennas were mounted flush with the missile surface, two for transmission and two for reception. Figure 3-1 is a block diagram of this equipment. The subsystem was designed to operate for the expected 21-day orbital life of the missile. Because of the short lifetime, batteries alone were the power source; thus, the complexity of solar cells and rechargeable batteries was avoided. Table 3-1 gives details about Project SCORE.

Each half of the communication subsystem had a tape recorder with a four-min capacity. Any of the four ground stations in the southern U.S. could command the satellite into a playback mode to transmit the stored message or into a record mode to receive and store a new message. A real-time mode was also available in which the recorder was bypassed. About eight hours of actual operation occurred before the batteries failed. During this time, voice, single channel teletype, and frequency-multiplexed six-channel teletype signals were transmitted to the satellite, recorded, stored, and later retransmitted. One of the signals handled in this manner was a Christmas message of President Eisenhower. In addition to the stored mode transmissions, there were several real-time transmissions through the satellite.

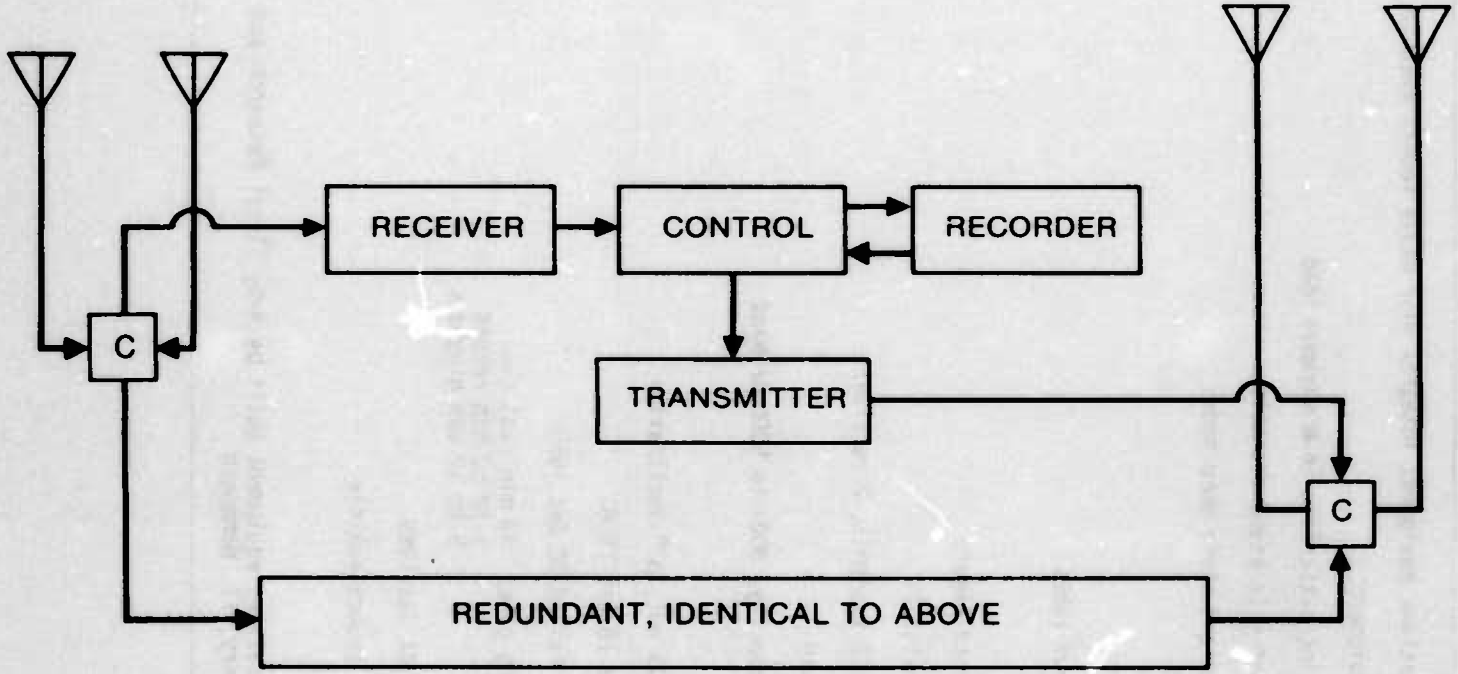

Figure 3-1. SCORE Communication Subsystem

Table 3-1. SCORE Details

Satellite	Communications equipment integral with Atlas launch vehicle
	99 lb equipment
	Silver-zinc batteries, 56-W maximum load
Capacity	1 voice or 6 teletype channels
	Real-time and store-dump modes
Transmitter	132 MHz
	8-W output
	All vacuum tubes
Receiver	150 MHz
	10-dB noise figure
	All transistors
Antenna	4 slots (2 transmit, 2 receive)
	-1 dB gain
Recorder	4-min capacity, 300- to 5000-Hz band
Design Life	2 weeks
Orbit	100 x 800 nmi, 32^{o} inclination
Orbital History	Launched 18 Dec 1958
	Battery failed 30 Dec 1958
	Operating time: 43 min real time 1 hr 52 min record 5 hr 12 min playback
	Decayed 21 Jan 1959
	Atlas B launch vehicle
Developed by	ARPA
	Communications equipment built by Army Signal Research and Development Laboratory, Ft. Monmouth

3.2 ECHO (Refs. 4, 13-18)

During the late 1950s and early 1960s, the relative merits of passive and active communication satellites were often discussed. Passive satellites merely reflect incident radiation, whereas active satellites have equipment that receives, processes,* and retransmits incident radiation. At the time of Project Echo, the main advantages given for passive satellites were: very wide bandwidths, multiple access capability, and no chance for degradations due to failures of satellite electronics. The disadvantages were: the lack of signal amplification, the relatively large orbit perturbations resulting from solar and atmospheric effects (because of the large surface-to-weight ratio), and the difficulty in maintaining the proper reflector shape. The progress in active satellites soon overshadowed the possible advantages of passive satellites, and interest in passive satellites ceased in the mid-1960s. In the mid-1970s, there was some interest in passive satellites concerning their use in a nuclear war environment.

Project Echo produced two large spherical passive satellites that were launched in 1960 and 1964 (see Table 3-2 for details). Echo 1 was used for picture, data, and voice transmissions between a number of ground terminals in the United States. In addition, some transmissions from the U.S. were received in England. A number of modulation methods were tested during the Echo 1 experiments, and valuable experience was gained in the preparation and operation of the terminals, especially in tracking the satellites. In addition to the communications experiments, Echo 1 was used for radar and optical measurements, and its orbital data were used to calculate atmospheric density.

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*The processing may be only amplification and frequency translation, or it may include additional operations.

Echo 2 had a slightly different design to provide a stiffer and longer lasting spherical surface. It was used very little for communications, although some one-way transmissions were made from England to the U.S.S.R., but it was used in other scientific investigations similar to those performed with Echo 1.

Table 3-2. Echo Details

Satellite	Echo 1: Sphere, 100-ft diameter, 166 lb Echo 2: Sphere, 135-ft diameter, 547 lb Not stabilized Aluminized mylar surface, maximum reflectivity 98% for frequencies up to 20 GHz
Frequencies Used	1: 960 and 2390 MHz 2: 162 MHz
Orbit	1: 820 x 911 nmi, 48.6^o inclination (initial values) 2: 557 x 710 nmi, 85.5^o inclination (initial values)
Orbital History	1: Launched 12 Aug 1960 Decayed 25 May 1968 2: Launched 25 Jan 1964 Decayed 7 Jun 1969 Delta launch vehicle
Developed for	NASA Langley Research Center (1); NASA Goddard Space Flight Center (2)
Developed by	G. T. Schjeldahl Company (balloon) Grumman (dispenser)

3.3 COURIER (Refs. 19-21)

The purpose of the Courier program was to develop a satellite of higher capacity and longer life than SCORE, which could be used for communication tests and assessments of traffic handling techniques. The concept was similar to SCORE in that the primary operating mode was store-and-dump using onboard tape recorders. A real-time mode was also available. Unlike SCORE, Courier was a self-contained satellite, and had both solar cells and rechargeable batteries for power supply (see Table 3-3 for details). Except for the final amplifiers of the transmitters, the electronics were all solid state.

The Courier communication subsystem (Figure 3-2) had four receivers, two connected to each antenna. Signals received through the two antennas were summed in a baseband combiner. The satellite could support a single half-duplex voice in the real-time mode. One analog and four digital recorders, each with a four-min recording capability, were used for the store-and-dump mode. This allowed any ground terminal to use the satellite for transmission of four separate digital (multiplexed teletype) messages, one to each of four other terminals. Upon command, a recorded message (or the received signal in the real-time mode) would modulate two transmitters, one connected to each antenna. The satellite also had two spare transmitters. The two carrier frequencies were separated about 20 MHz. Various signal combining techniques were used at the ground to make use of these two signals.

The first Courier launch was unsuccessful due to a booster failure. The second, in October 1960, was a success. Communication tests were performed by two ground terminals, located in New Jersey and Puerto Rico. The satellite performed satisfactorily until 17 days after the launch, when communications were stopped by a command system failure.

Table 3-3. Courier Details

Satellite	Sphere, 51-in. diameter
	500 lb in orbit
	Solar cells and NiCd batteries, 60 W
Capacity	Real time: 1 voice channel
	Store-dump: 13.2 Mb/recorder digital, 4-min voice
Transmitter	1700- to 1800-MHz band
	2 transmitters on, 2 standby
	Solid state except output tubes
	2-W output per transmitter
Receiver	1800- to 1900-MHz band
	2 receivers on, 2 standby
	All solid state
	14-dB noise figure
Antenna	2 slots at antipodal points, used for both transmit and receive
	-4 dB gain
	Linear polarization
Recorders	4 digital: each 4 min at 55 kbps (13.2 Mb total)
	1 analog: 4-min capacity, 300 to 50,000 Hz
Design Life	1 yr
Orbit	525 x 654 nmi, 28° inclination
Orbital History	1A: Launch vehicle failure
	1B: Launched 4 Oct 1960 Operated 17 days
	Thor-Able Star launch vehicle
Developed by	Army Signal Research and Development Laboratory

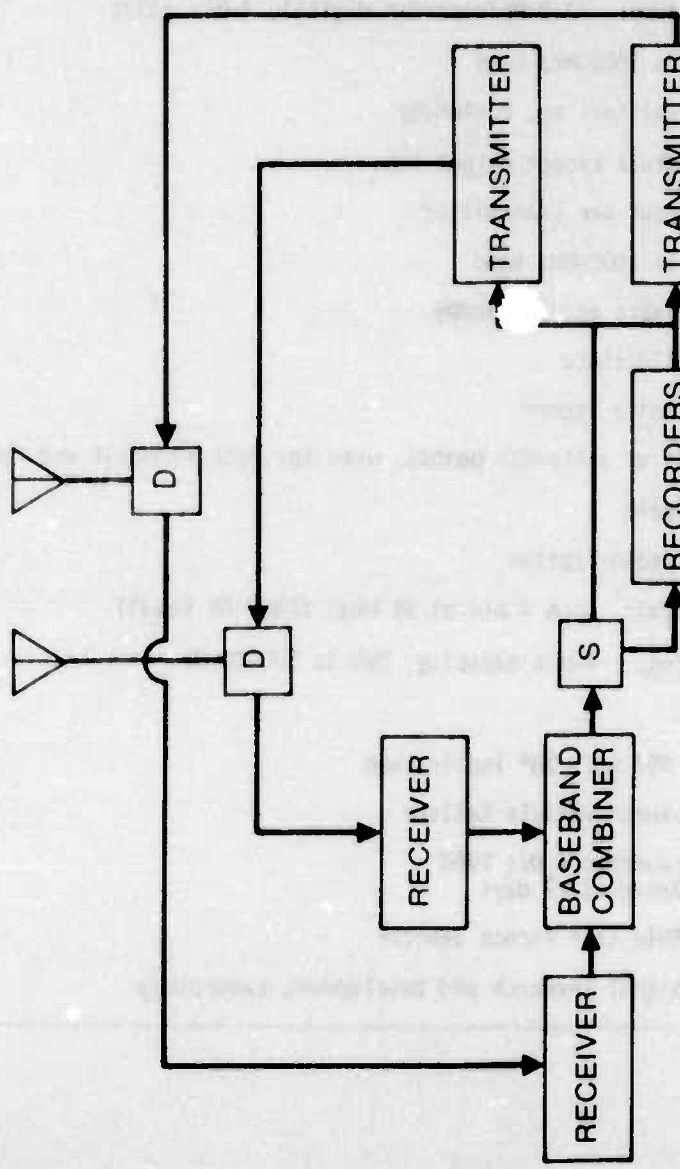

Figure 3-2. Courier Communication Subsystem

3.4 WEST FORD (Refs. 22-23)

The West Ford concept grew out of a 1958 summer study on secure, hard, reliable communications. The conclusions reached were as follows: first, use satellites and microwave frequencies for long distance communications; second, put all active equipment on the ground for reliability; and third, use a belt of dipoles instead of a single satellite for hardness. When the concept was defined openly, there was some adverse reaction because of the uncertain effects on optical and radio astronomy. After some time the project was allowed to proceed under certain restrictions.

West Ford and Echo were the only two passive communication reflectors put into orbit. Echo could rightly be called a satellite, but the West Ford reflector consisted of 480 million copper dipoles about 0.75 in. long. The length was chosen to correspond to a half wavelength of the 8-GHz transmission frequencies used in the program. Other West Ford details are given in Table 3-4.

The dipoles were dispensed from an orbiting container in May 1963. Initially, all were concentrated in one portion of the orbit. During the first few weeks, voice and frequency shift keying (FSK) data up to 20 kilobits per second (kbps) were transmitted from Camp Parks (Pleasanton, California) to Millstone Hill (at Westford, Massachusetts - the source of the project name). Four months later, when the belt was fully extended, the density was much lower, and only 100-bit-per-second (bps) data were transmitted. Because of this low capacity and the increasing performance of active satellites, no further experiments of this type were attempted.

Table 3-4. West Ford Details

Satellite	480 million copper dipoles, each 0.72 in. long, 7×10^{-4}-in. diameter 88 lb in orbit
Frequency Used	8350 MHz
Orbit	1970-nmi nominal altitude Nearly circular, nearly polar Dispersion: 8 nmi cross-orbit, 16 nmi radially, 1300-ft average distance between dipoles
Orbital History	First: Launched 21 Oct 1961 Dispenser did not release dipoles Second: Launched 9 May 1963 Fully dispersed Aug 1963 Atlas-Agenda B launch vehicle
Developed by	MIT Lincoln Laboratory

3.5 TELSTAR (Refs. 4, 24-29)

The Telstar experiment grew out of the Bell Systems interest in overseas communication. Bell Telephone Laboratories (BTL) was a major participant in communication experiments using Echo 1. The positive results of those experiments strengthened the interest in satellite communications generated by earlier analytical papers. Therefore, American Telephone and Telegraph Company (AT&T) decided to build an experimental active communication satellite. The objectives of the Telstar program were as follows:

a. Look for the unexpected.
b. Demonstrate transmission of various types of information via satellite.
c. Build a large ground antenna and learn how to use it.
d. Gain experience in satellite tracking and orbital predictions.
e. Study Van Allen radiation belt effects.
f. Face the design problems required for a spaceborne repeater.

An active satellite was decided on because the required balloon size for TV bandwidths was much beyond the state of the art. The choice of the Delta launch vehicle provided basic design constraints such as size, weight, and orbit. In accordance with objective e, the satellite contained a number of sensors to make radiation measurements. Objective c was accomplished by the construction and use of a ground station at Andover, Maine.

Two Telstar satellites were produced. Figure 3-3 is a picture of one of them and Table 3-5 gives program details. The satellites were 34.5-in. diameter spheres with solar cells covering most of the outer surface. The solar array output alone could not support operation of the communication subsystem, so batteries were used to supply the peak power requirements. The batteries were recharged during the periods when the satellite was not in view of the ground terminals and the communication subsystem was turned off. This

subsystem had a single channel with a 50-MHz bandwidth. A block diagram is given in Figure 3-4.

Telstar 1 was launched in June 1962. In the following six months, about 400 transmission sessions were conducted with multichannel telephone, telegraph, facsimile, and television signals. In addition, over 250 technical tests and measurements had been performed. Stations in the U.S., Britain, and France participated in these activities. In November 1962 the command subsystem on the satellite failed. The cause was later established as degradation of transistors due to Van Allen belt radiation. Various operations effected a recovery that allowed the satellite to be used for another month and a half early in 1963, after which the command subsystem failed again.

Telstar 2 was nearly identical to Telstar 1. The only significant design change was the use of radiation resistant transistors in the command decoders. The Telstar 2 satellite orbit had a higher apogee than Telstar 1, which increased the time in view of the ground stations and decreased the time in the Van Allen belts. Telstar 2 was launched in May 1963 and operated successfully for two years.

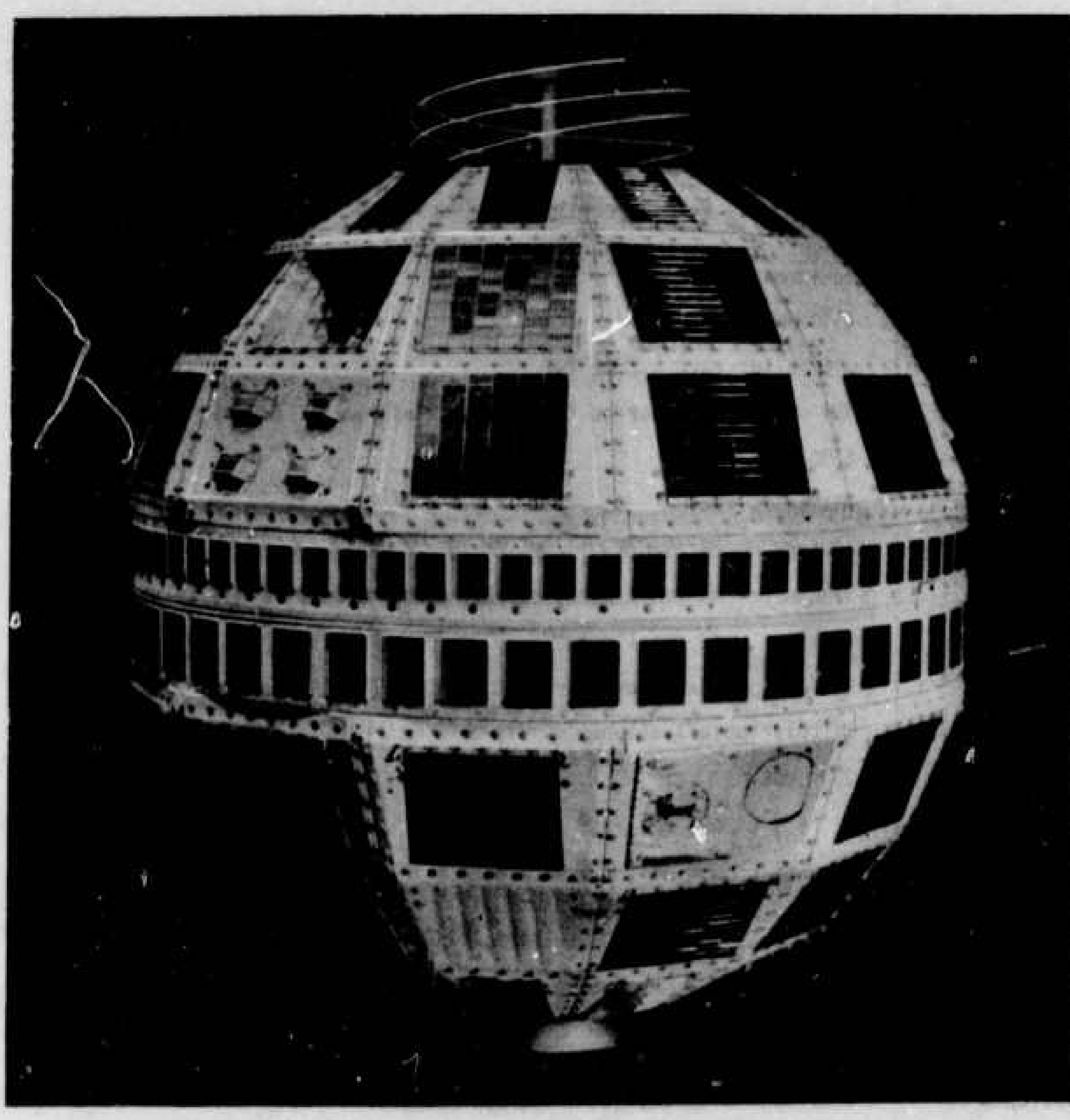

Figure 3-3. Telstar Satellite

Table 3-5. Telstar Details

Satellite	Sphere, 34.5-in. diameter
	1: 170 lb in orbit
	2: 175 lb in orbit
	Solar cells and NiCd batteries, 15 W
	Spin-stabilized, 200 rpm
Configuration	One 50-MHz bandwidth double conversion repeater
Capacity	600 one-way voice circuits or 1 TV channel
	60 two-way voice circuits (tests limited to 12 circuits by ground equipment)
Transmitter	4170 MHz
	All solid state except TWT
	TWT operated linear at 3.3 W (saturated power: 4.5 W)
Receiver	6390 MHz
	All solid state
	12.5-dB noise figure
Antenna	Transmit: 48 small ports equally spaced around satellite waist
	Receive: 72 small ports
	Uniform pattern around waist and $\pm 30^{\circ}$ from waist plane
	Circular polarization
Design Life	2-yr goal
Orbit	1: 514 x 3051 nmi, 45° inclination
	2: 525 x 5830 nmi, 43° inclination
Orbital History	1: Launched 10 Jul 1962 Operated until 23 Nov 1962, and 4 Jan to 21 Feb 1963
	2: Launched 7 May 1963 Operated until May 1965
	Delta launch vehicle
Developed for	American Telephone and Telegraph Company
Developed by	Bell Telephone Laboratories

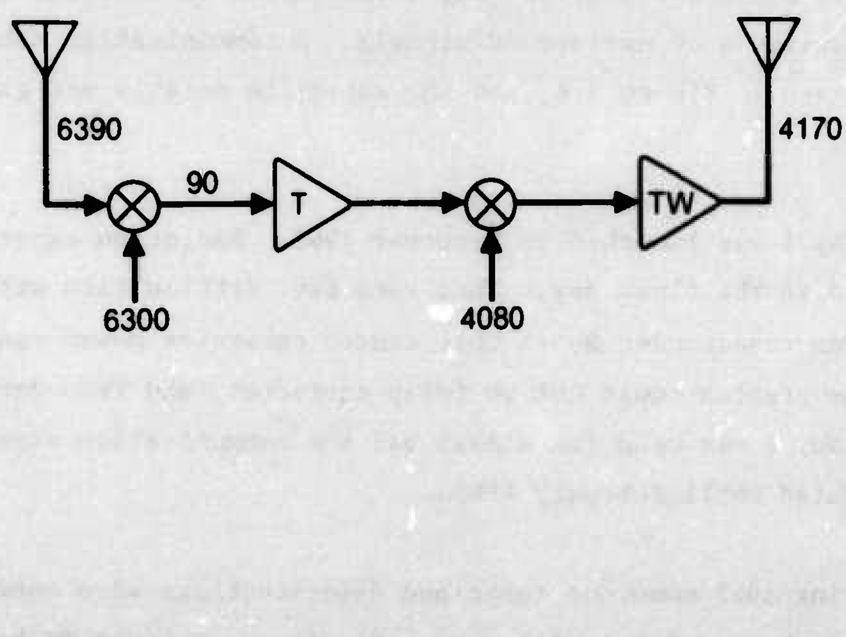

Figure 3-4. Telstar Communication Subsystem

3.6 RELAY (Refs. 4, 25, 30-34)

The Relay program was undertaken by the National Aeronautics and Space Administration (NASA) to perform active satellite communications and to measure Van Allen belt radiation and its effect on satellite electronics. Basic objectives were to transmit telephone and television signals across the Atlantic and to transmit telephone signals between North and South America. During the time the satellite was being developed, foreign governments were invited to participate in communications experiments. Primary ground stations were in Maine, England, and France - the same stations that conducted demonstrations with Telstar 1. Other ground stations were in California, New Jersey, Germany, Italy, Brazil, and Japan.

The Relay satellite (shown in Figure 3-5) had a more complex commmunication subsystem then Telstar, with two identical redundant repeaters. Either repeater could be connected to the common antennas by ground command. Each repeater had one 25-MHz channel and two 2-MHz channels. These channels allowed either one-way transmission of wideband signals or two-way transmission of narrowband signals. A communication subsystem block diagram is given in Figure 3-6, and the satellite details are given in Table 3-6.

Relay 1 was launched in December 1962. Radiation experiment data were obtained in the first day. That same day, difficulties with communications transponder No. 1 that caused excessive power consumption were noticed. The problem could not be fully corrected, and from January 1963 transponder No. 2 was used for almost all the communication experiments. Relay 1 operated until February 1965.

During 1963 numerous tests and demonstrations were conducted including telephone and television transmissions. Network TV broadcasts were transmitted from the U.S. to Europe and to Japan. Several times both television and telephone transmissions were used for international medical

consultations. In October 1964 television coverage of the Olympic games was relayed from Japan to the U.S. by Syncom 3 and then from the U.S. to Europe by Relay 1.

Relay 2 was modified slightly to provide increased reliability and radiation resistance. Relay 2 was launched in January 1964 and was used in a variety of communications tests similar to those done with Relay 1. By July 1964, Relay 1 and 2 had been used for 112 public demonstrations of telephone and television transmission. Relay 2 was used until May 1965.

The Telstar and Relay programs were both considered successful. They demonstrated that the technology at that time could produce a useful, medium altitude communication satellite. In addition, ground station technology was proven, and routine operation of ground stations was demonstrated. Measurements of communications parameters indicated no significant deviations from theoretically expected values. Finally, it was shown that satellite communication systems could share frequencies with terrestrial microwave systems without mutual interference.

Figure 3-5. Relay Satellite

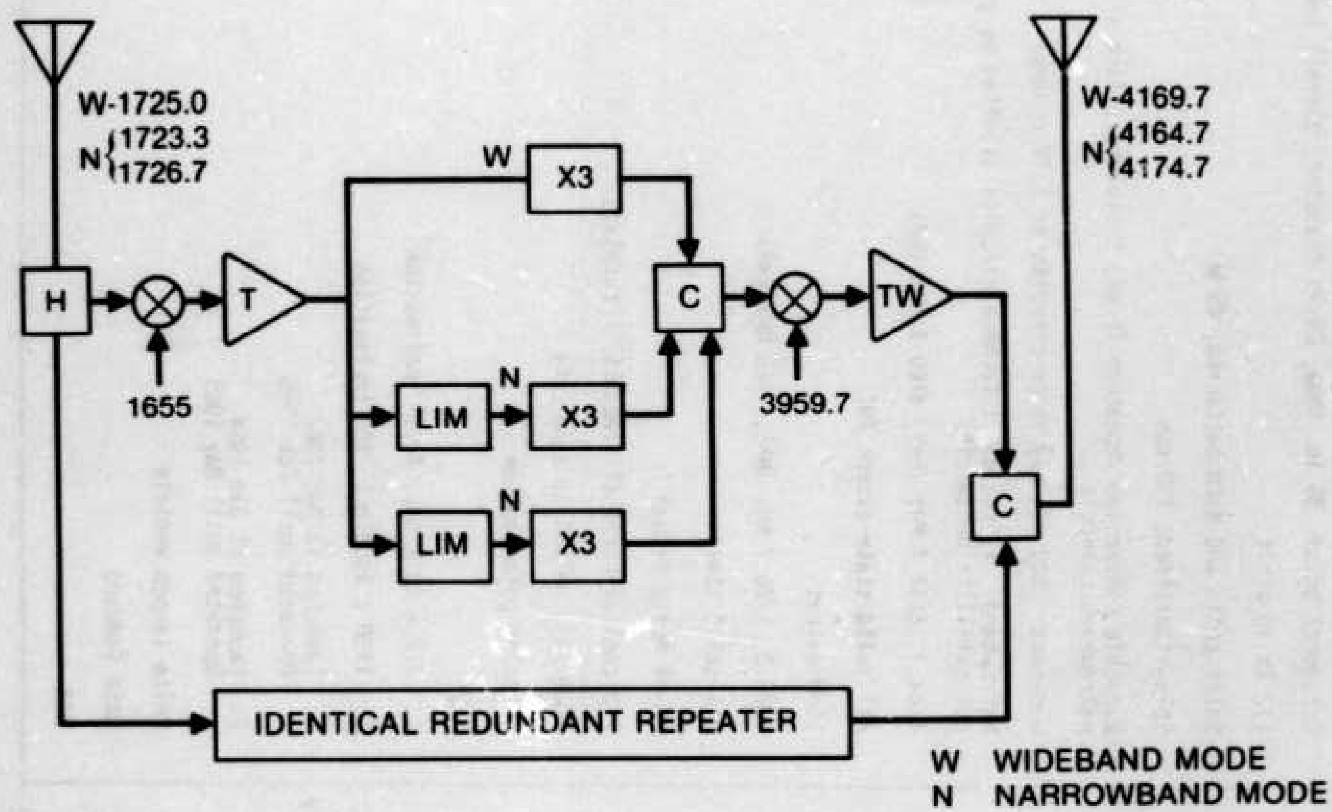

Figure 3-6. Relay Communication Subsystem

Table 3-6. Relay Details

Satellite	Octagonal prism, 35 in. long, 29-in diameter, overall length 53 in. 172 lb in orbit Solar cells and NiCd batteries, 45 W Spin-stabilized, 150 rpm
Configuration	2 double conversion repeaters (1 on, 1 standby), each with 1 wideband or 2 narrowband channels
Capacity	Wideband: 300 one-way voice circuits or 1 TV channel Narrowband: 12 two-way telephone circuits (limited by ground equipment, not satellite bandwidth)
Transmitter	4164.7, 4174.7 MHz (NB), 4169.7 MHz (WB) All solid state except TWT 10-W output
Receiver	1723.3, 1726.7 MHz (NB), 1725 MHz (WB) All solid state 14-dB noise figure
Antenna	2 biconical horns (1 transmit, 1 receive) ~0dB gain normal to spin axis Circular polarization
Design Life	1 yr
Orbit	1: 712 x 4012 nmi, 47.5° inclination 2: 1130 x 4000 nmi, 46° inclination
Orbital History	1: Launched 13 Dec 1962 Operated until Feb 1965 2: Launched 21 Jan 1964 Operated until May 1965 Delta launch vehicle
Developed for	NASA Goddard
Developed by	RCA

3.7 SYNCOM 1 TO 3 (Refs. 4, 31, 35-40)

In the early 1960s, both medium and synchronous altitude communication satellites were of interest to planners. The National Aeronautics and Space Administration (NASA) conducted experiments at both altitudes using the Relay and Syncom satellites. The Syncom program had three major objectives:

a. Place a satellite in synchronous orbit.
b. Demonstrate on-orbit stationkeeping.
c. Make engineering measurements on a synchronous altitude communication link.

The Syncom satellite (Figure 3-7) had a short cylindrical body that was spun about its axis to provide stabilization in orbit. The antennas were mounted beyond one end of the body and were colinear with the satellite axis. All the satellite equipment was contained within the body. This design formed the basis for many later synchronous altitude satellites. Details are given in Table 3-7. The communication subsystem (Figure 3-8) had two receivers and two transmitters for redundancy; either receiver could be operated with either transmitter. The channelization was similar to Relay, with two 500-kHz channels for narrowband two-way communications and one 5-MHz channel for one-way wideband transmissions. (These capabilities could not be used simultaneously.)

Syncom 1 was launched in February 1963. The intended orbit was at synchronous altitude with a 33-deg inclination. The satellite operated properly during the ascent, but all communication was lost when the apogee motor fired to inject the satellite into its final orbit. The cause of the failure was the rupturing of a tank of nitrogen which was part of the on-orbit control subsystem. Syncom 2 was successfully launched in July 1963. Like Syncom 1, it was not intended to achieve a stationary synchronous orbit because of the extra propellant weight and control complexity required to attain zero-deg inclination. NASA conducted a number of tests using this satellite, including voice, teletype, and facsimile. During its first year,

in addition to engineering tests, 110 public demonstrations were conducted. Their purpose was to acquaint the public with communication satellites and to gain a broader based, subjective appraisal of system performance.

Syncom 3 was launched in August 1964. By this time, launch vehicle technology had progressed to the point where a true synchronous equatorial (inclination $< 1^{o}$) orbit was possible. The only major change in the communication equipment was a channel, with greater bandwidth than Syncom 2, to be used for television transmissions.

The Department of Defense (DoD) also conducted a number of tests using Syncom 2 and 3. During 1965 and 1966 both were used extensively. Five ground stations and one shipborne terminal were in regular system use. Also, tests with aircraft terminals were conducted using the VHF command and telemetry links. By February 1966 the Syncom 2 and 3 repeaters had a cumulative operational time of 27,000 hr. DoD use of Syncom diminished when the Initial Defense Communication Satellite Program (IDCSP) satellites became operational.

While the Syncom satellites were being developed and tested, an Advanced Syncom study was also being conducted.* The conceptual satellite was larger than Syncom, generated more prime power, had higher antenna gain, and had repeaters of two different designs. This program grew beyond an advanced communications experiment and became the Applications Technology Satellite (ATS) program.

*The Advanced Syncom program was sometimes called Syncom II, which, in some references, is difficult to distinguish from the second satellite of the original Syncom program (Syncom 2 in this text).

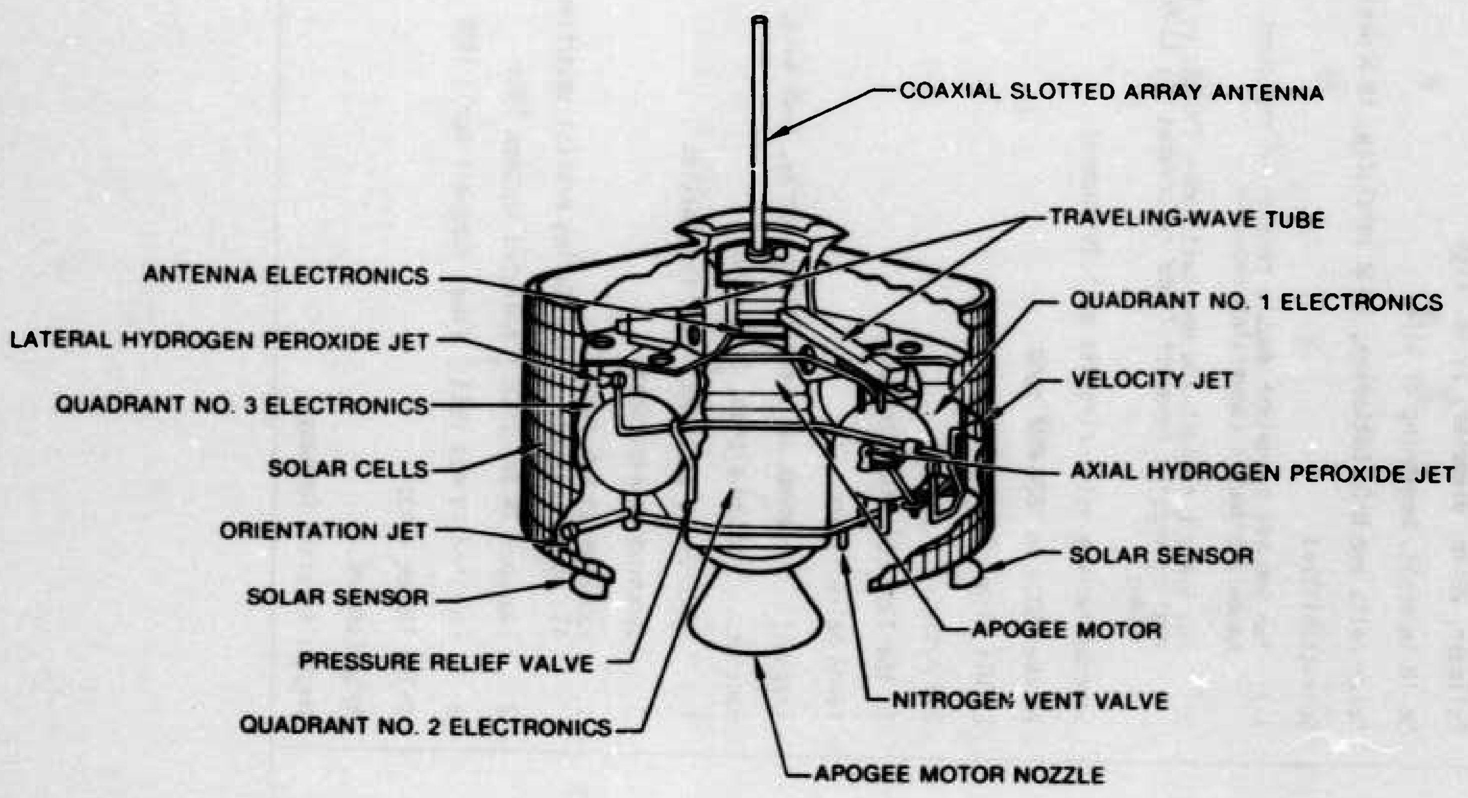

Figure 3-7. Syncom Satellite

Table 3-7. Syncom Details

Satellite	Cylinder, 28-in. diameter, 15 in. high 36 lb in orbit, beginning of life Solar cells are NiCd batteries, 28 W initially, 19 W minimum after 1 yr Spin-stabilized
Configuration	1-2: Two 500-kHz bandwidth double conversion repeaters, or one 5-MHz bandwidth double conversion repeater 3: One 5-MHz bandwidth and one switchable (50-kHz or 10-MHz) bandwidth dual conversion repeater (some references say 13-MHz instead of 10-MHz)
Capacity	Several two-way voice circuits or 1 TV channel
Transmitter	In the 1800- to 1820-MHz band 2 TWTs (1 on, 1 standby) 2-W output
Receiver	In the 7350- to 7370-MHz band 10-dB noise figure
Antenna	Transmit: 3-element colinear slotted array, 6-dB gain, $23^{\circ} \times 360^{\circ}$ beam Receive: Slotted dipole, 2-dB gain
Orbit	1-2: Synchronous altitude, $\sim 32^{\circ}$ inclination 3: Synchronous equatorial
Orbital History	1: Launched 13 Feb 1963 All communications failed during orbital insertion 2: Launched 26 Jul 1963 | operated through 1966 3: Launched 19 Aug 1964 | final turn-off April 1969 Delta launch vehicle
Developed for	NASA Goddard
Developed by	Hughes Aircraft Company

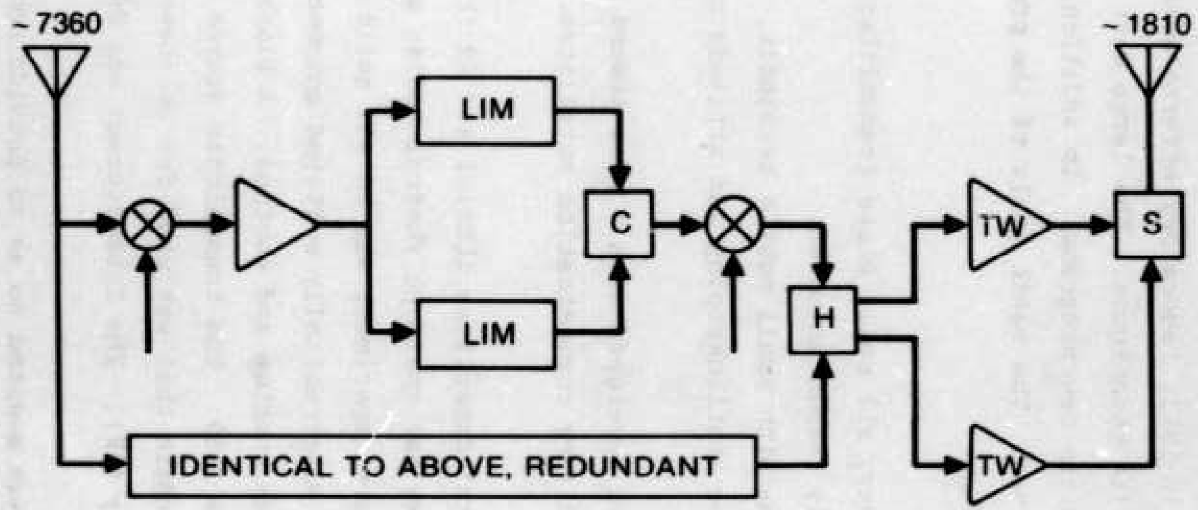

Figure 3-8. Syncom Communication Subsystem

3.8 LINCOLN EXPERIMENTAL SATELLITES (LES)-1 TO -7 (Refs. 41-46)

The Massachusetts Institute of Technology (MIT) Lincoln Laboratory has been active for a long time in various aspects of military communications. Early work in ionospheric and tropospheric scatter communications evolved into the West Ford orbital scatter program. At the conclusion of that program in 1963, laboratory efforts were directed into active communication satellite techniques. The large West Ford ground stations were to be used in the new programs. In addition, smaller mobile terminals were to be developed. The basic goals of the program included demonstration of the following:

a. High efficiency, all solid state transmitters.
b. Electronically despun antennas.
c. Communications with small mobile terminals.
d. Techniques for stationkeeping and attitude control.

Experimental techniques were developed with a view toward eventual application in synchronous altitude military communication satellites.

Lincoln Experimental Satellites (LES)-1 and -2 (Figure 3-9) were essentially identical. They had small polyhedral bodies and were spin-stabilized. The primary experiment was an all solid state X-band repeater and an eight-horn electronically switched antenna. The other experiments were in attitude sensing and control. A block diagram of the repeater is shown in Figure 3-10. The transmitter source was a crystal oscillator and multiplier chain that was used for upconversion of the signal from intermediate frequency (IF). The X-band power was 200 mW.

The eight horns were mounted so as to provide omnidirectional coverage. Sensors were used to determine the direction of the earth and the satellite spin rate. Onboard logic then controlled switches to use the antenna most closely pointed toward the center of the earth. Other details of LES-1 and -2 are given in Table 3-8.

LES-1 was launched in February 1965. A launch vehicle failure left the satellite in the wrong orbit. Limited tests were run, which indicated that the repeater and the switched antennas were operating properly. The satellite then entered a tumbling mode that ended its usefulness. LES-2 was launched in May 1965 and operated as planned until it was turned off in September 1966.

LES-3 was not a communication satellite; its purpose was to transmit an ultrahigh frequency (UHF) signal for propagation measurements. The LES-4 satellite (Figure 3-11) was similar to LES-1 and -2. The interior structure was the same, but the solar array was mounted on a cylindrical shell rather than on a polyhedral shell, the cylindrical array being more efficient for the synchronous equatorial orbit of LES-4. Table 3-9 gives details about the satellite. The LES-4 repeater design was nearly the same as the LES-2 design (Figure 3-10), but improved components significantly lowered the receiver noise figure and increased the transmitter power.

The LES-4 transmitting antenna was composed of eight horns uniformly spaced in a plane normal to the satellite spin axis. Sun and earth sensors and logic circuits controlled the switches to despin the antenna electronically. The difference in antenna design from LES-2 was possible because LES-4 was intended for use in a synchronous equatorial orbit where coverage could be limited to 26 deg in the north-south plane.

LES-3 and -4 were launched in December 1965. As the result of a launch vehicle malfunction, the satellites were placed in an elliptical synchronous transfer orbit. Initially the orientation of LES-4 was such that only enough power was available for operation of the telemetry system. Five days after launch, the spin axis orientation had changed enough so that power was available for the operation of all the satellite systems. From that time, the LES-4 repeater and antenna operated as expected.

The LES-5 and -6 satellites had cylindrical shapes with equipment mounted on a platform near the center of the cylinder and normal to its axis (Figure 3-12). Both had multiple element antennas mounted around the cylindrical surface. In addition to their communications equipment, the satellites carried solar cell degradation and radio frequency interference (RFI) experiments. LES-6 also had a prototype autonomous stationkeeping subsystem. Details of LES-5 and -6 are given in Tables 3-10 and 3-11.

LES-5 and -6 had all solid state communications equipment that operated in the military UHF band.* The LES-5 communication subsystem is shown in Figure 3-13. It had a final amplifier of conventional design and had very good efficiency - 68 percent direct current (DC) to radio frequency (RF). The LES-6 amplifier was an experimental design in that it was directly connected to the solar arrcy power bus without any intervening power converters. In this design all power not required by other satellite systems is directly available to the transmitter, and the transmitter power varies with the available prime power. It is claimed that this design provides an extra 3 dB of transmitted power initially and 0.5 dB extra at the end of satellite life. In-orbit measurements indicated that transmitter power was in the range of 100 to 130 W. LES-5 did not have a despun antenna, but it was used to test some logic that was used in LES-6. The despun circuitry in LES-6 was based on LES-2 and -4 experience and used similar techniques involving earth and sun sensors.

LES-5 was launched in July 1967 with three IDCSP satellites and was placed into a subsynchronous orbit similar to theirs. Both Lincoln Laboratory and the military services conducted a number of tests with LES-5. Aircraft, shipborne, and fixed and mobile ground terminals were all involved in the tests, which were considered very successful. LES-5 operated until May 1971.

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*This is called UHF although the standard designation is very high frequency (VHF) up to 300 MHz and UHF above that.

LES-6 was launched in September 1968 and was used in tests similar to those conducted with LES-5. The satellite operated satisfactorily. The communication subsystem continued in active use, although by 1975 the effective radiated power (ERP) had decreased 8 dB from its initial value It was turned off early in 1976 to avoid any frequency conflict with the Marisat launched in February 1976. The LES-6 communication subsystem is shown in Figure 3-14.

The LES-7 satellite was intended to have an all solid state, 100-MHz bandwidth, single conversion, X-band repeater and a multibeam antenna. Although the program was canceled before the satellite was built, a prototype antenna was built and tested. This antenna was a waveguide lens-type with a cluster of 19 feed horns, and was capable of generating beam sizes as small as 3 deg and as large as earth coverage.

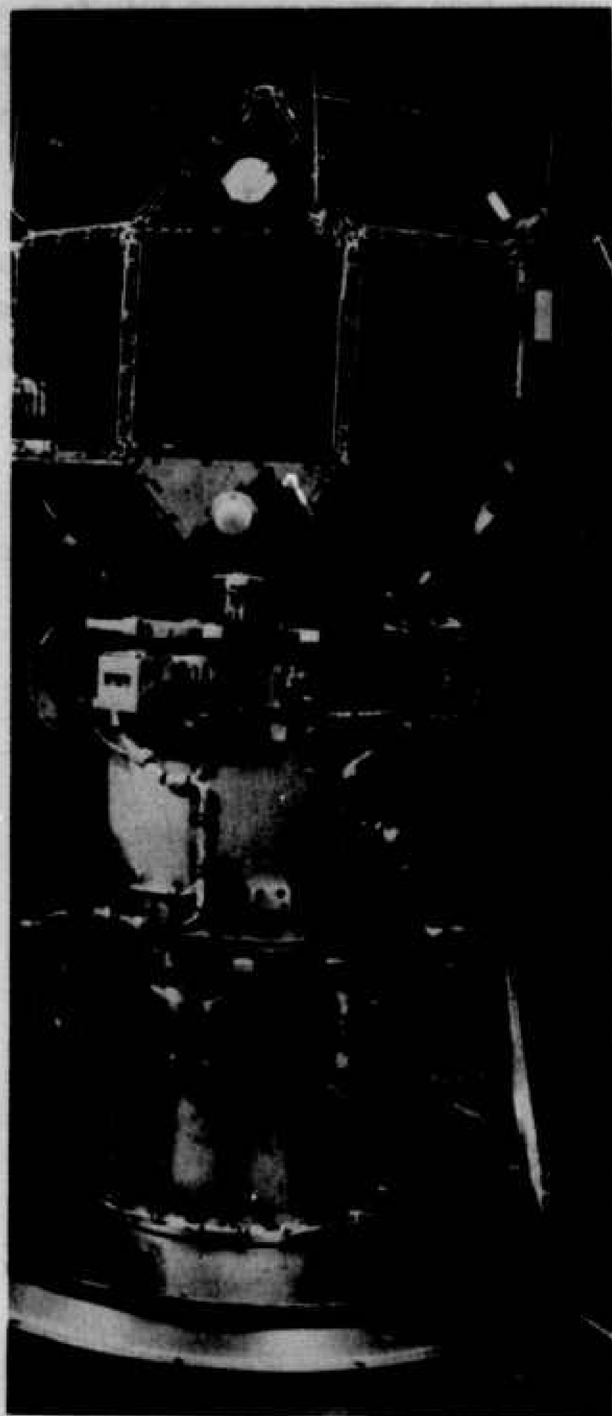


Figure 3-9. LES-1 Satellite

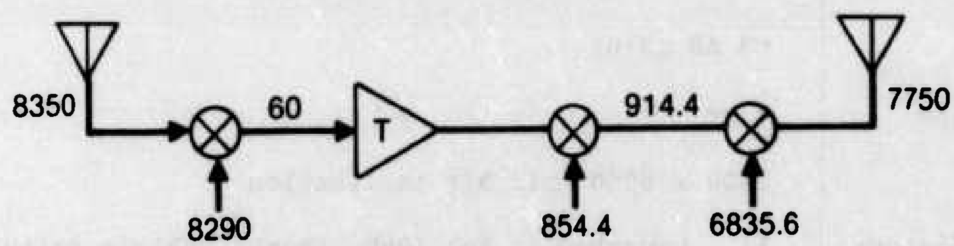


Figure 3-10. LES-1, -2, and -4 Communication Subsystem

Table 3-8. LES-1 and -2 Details

Satellite	26-sided polyhedron, ~24 in. each dimension
	82 lb in orbit
	Solar cells, 25 W beginning of life, no batteries
	Spin-stabilized, 180 rpm
Configuration	20-MHz bandwidth triple conversion repeater
Transmitter	7750 MHz (CW beacon at 7740 MHz)
	All solid state
	200-mW output, 115 mW at antenna
Receiver	8350 MHz
	16-dB noise figure
	G/T: -37 dB/$^{\circ}$K, maximum
Antenna	8 horns, electronically switched (only 1 used at a time)
	~3 dB gain
Design Life	2 yr
Orbit	1500 x 8000 nmi, 32° inclination
Orbital History	1: Launched 11 Feb 1965, launch vehicle failure left satellite in 1500 x 1500-nmi orbit and tumbling
	2: Launched 6 May 1965, operated until Sep 1966, final turn-off May 1967
	Titan IIIA launch vehicle
Developed by	MIT Lincoln Laboratory

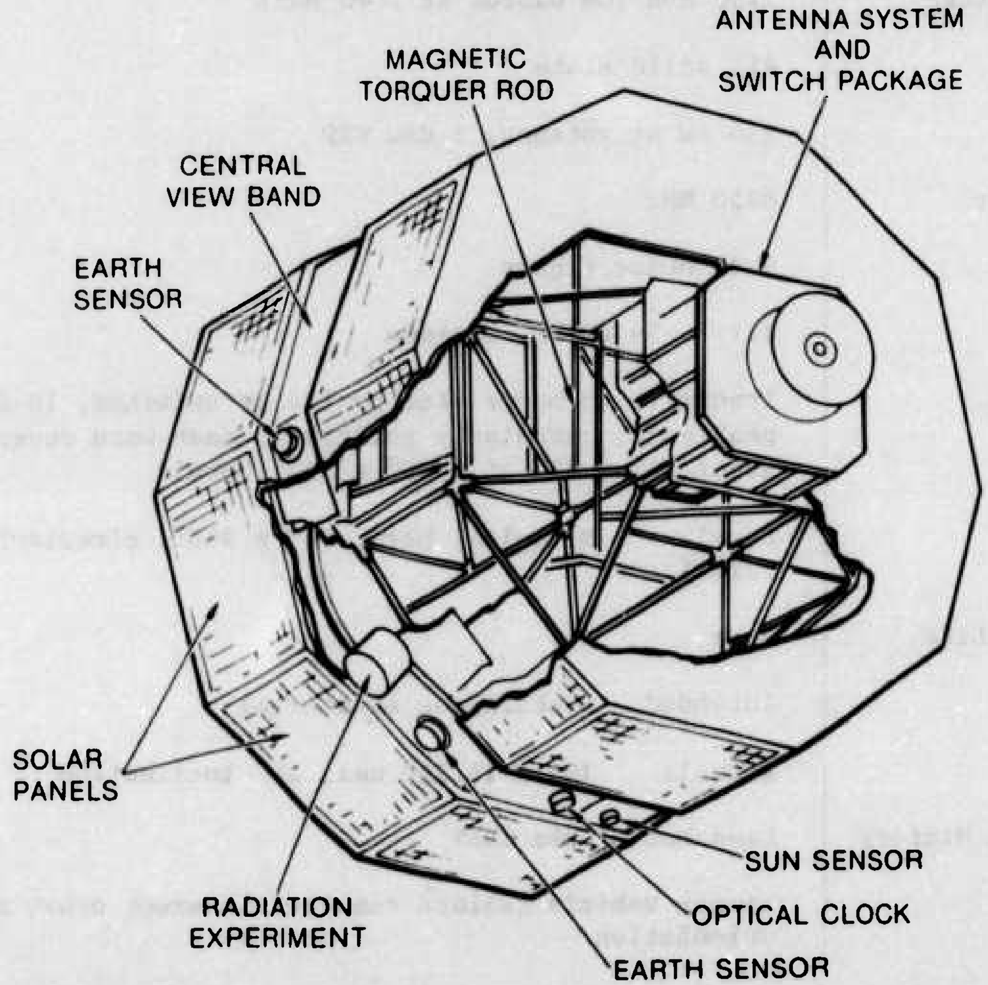


Figure 3-11. LES-4 Satellite

Table 3-9. LES-4 Details

Satellite	10-sided cylinder, 31-in. diameter, 25 in. high 116 lb in orbit Solar cells, 36-W initial minimum, no batteries Spin-stabilized, 11 rpm
Configuration	20-MHz bandwidth triple conversion repeater
Transmitter	7750 MHz (CW beacon at 7740 MHz) All solid state 230 mW at antenna, 3-dBW ERP
Receiver	8350 MHz 9-dB noise figure G/T: -29 dB/°K, maximum
Antenna	Transmit: 8 horns electronically switched, 10-dB peak gain, circularly polarized, each horn covered about 26° x 45° of a 26° x 360° toroid Receive: Biconical horn, 26° x 360°, circularly polarized
Design Life	3 yr
Orbit	Intended: Synchronous equatorial Actual: 105 x 18,200 nmi, 26° inclination
Orbital History	Launched 21 Dec 1965 Launch vehicle failure resulted in wrong orbit and orientation By 26 Dec 1965 the orientation changed enough to allow sufficient solar cell output for operation Titan IIIC launch vehicle
Developed by	MIT Lincoln Laboratory

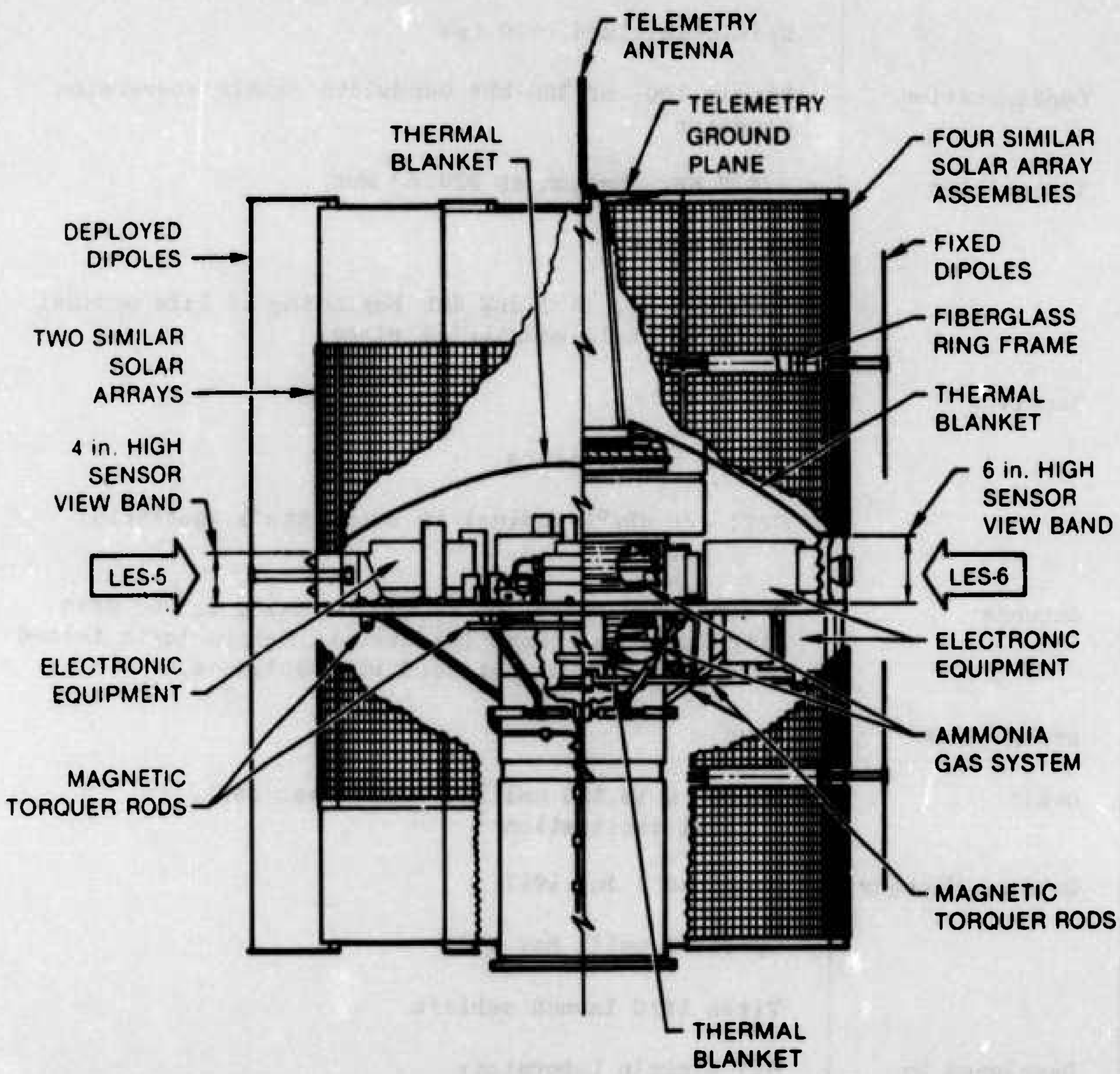


Figure 3-12. LES-5 and -6 Satellites

Table 3-10. LES-5 Details

Satellite	Cylinder, 48-in. diameter, 64 in. high 230 lb in orbit, beginning of life Solar cells, 136-W initial maximum, no batteries Spin-stabilized, ~10 rpm
Configuration	Single 100- or 300-kHz bandwidth double conversion repeater
Transmitter	228.2 MHz, beacon at 228.43 MHz Solid state 35-W output, 16.3-dBW ERP beginning of life nominal in satellite's equatorial plane
Receiver	255.1 MHz 3.6-dB noise figure G/T: -26 dB/^{o}K nominal in satellite's equatorial plane
Antenna	8 dipoles parallel to satellite axis, 2.5-dB gain circularly polarized (electronic despin logic tested on satellite, but not used with antennas)
Design Life	5 yr
Orbit	18,000 x 18,180 nmi (30^{o} drift per day), 7^{o} initial inclination
Orbital History	Launched 1 Jul 1967 Operated until May 1971 Titan IIIC launch vehicle
Developed by	MIT Lincoln Laboratory

Table 3-11. LES-6 Details

Satellite	Cylinder, 48-in. diameter, 66 in. high 398 lb in orbit, beginning of life Solar cells, 220-W initial maximum, limited battery capacity Spin-stabilized, ~8 rpm
Configuration	Single 100- or 500-kHz bandwidth double conversion repeater
Transmitter	249.1 MHz (500 kHz mode), 248.94 MHz (100 kHz mode), beacon at 254.14 MHz Solid state Variable output power, 120-W initial nominal (see text) ERP: 29.5 dBW at beginning of life, 21 dBW after 5 yr
Receiver	302.7 MHz (500 kHz mode), 302.54 MHz (100 kHz mode) 3.6-dB noise figure
Antenna	16 sets of dipoles and cavity backed slots arranged in 8 colinear pairs, circularly polarized Electronically despun, 9.5-dB gain, 34° (north-south) x 54° (equatorial plane) beamwidth
Orbit	Synchronous, 3° initial inclination
Orbital History	Launched 26 Sep 1968 Operated until turned off at the beginning of 1976, still operable in 1978 test Titan IIIC launch vehicle
Developed by	MIT Lincoln Laboratory

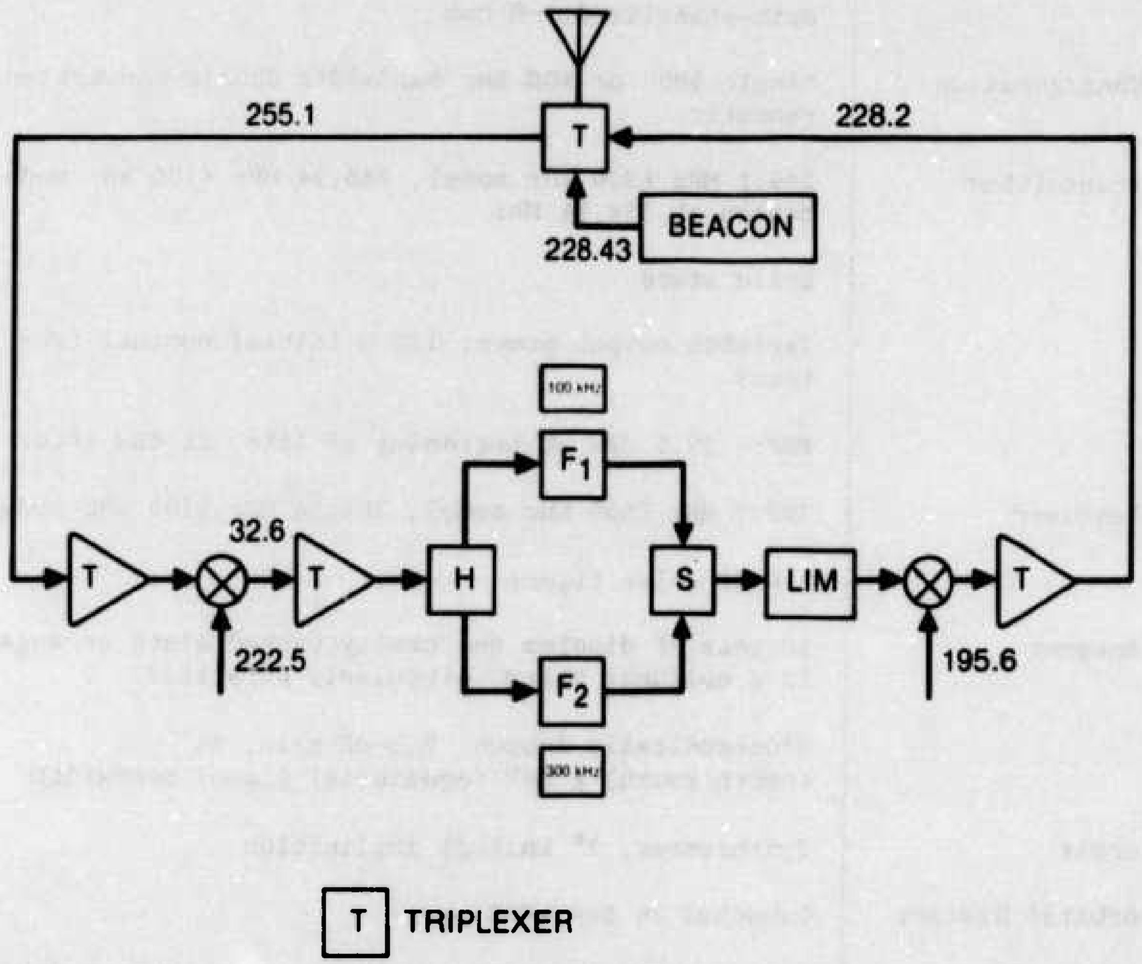


Figure 3-13. LES-5 Communication Subsystem

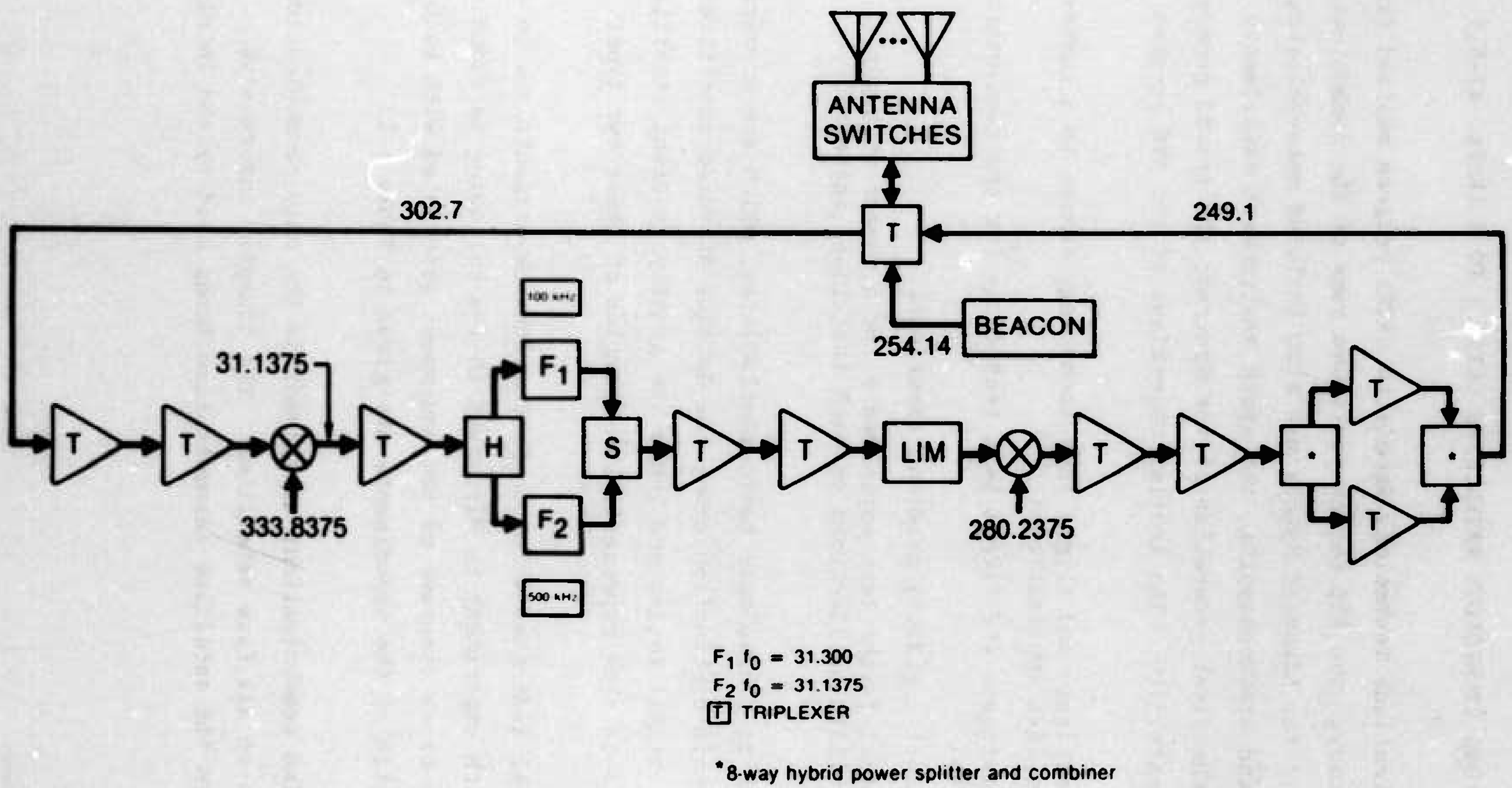


Figure 3-14. LES-6 Communication Subsystem

3.9 APPLICATIONS TECHNOLOGY SATELLITES (ATS) 1 TO 5 (Refs. 47-51)

The Applications Technology Satellite (ATS) program evolved from the Advanced Syncom study. The ATS series continued some of the communications experiments planned for Advanced Syncom and also included meteorological, attitude control and stationkeeping, and space environment experiments. ATS 1 to 5* constitute the first generation of the program; the second generation is the single ATS 6 satellite. The initial objectives of the ATS program were:

a. Investigate and flight test technology common to a number of satellite applications.

b. Investigate and flight test technology for the geosynchronous orbit.

c. Conduct a gravity gradient experiment.

d. Conduct flight test experiments for a number of types of satellite applications on each individual spacecraft.

The ATS 1 to 5 have some basic similarities, which are summarized in Table 3-12. The main distinction among the designs of these satellites is that two use spin stabilization and three use gravity gradient stabilization. Figures 3-15 and 3-16 show representative examples of these two types.

Table 3-12 indicates which communications experiments are in each satellite, and each experiment is discussed in the following sections. Figure 3-17 gives block diagrams of the equipment associated with each experiment. Details of the experiments are given in Table 3-13.

The C-band communications experiment is the only communications experiment common to all five satellites. The transmit and receive frequencies are in the satellite communication bands used by the Intelsat

*These satellites were known as ATS A, B, C, D, and E before launch.

satellites. Three modes of operation are possible in each of the two repeaters, and the repeaters may operate simultaneously. The frequency translation mode is used for wideband data relay between two ground stations. In this mode only one carrier is present, and the signal may occupy the entire 25-MHz repeater bandwidth. Several frequency division multiplexed, single-sideband modulated signals are received in the multiple access mode, and the composite signal is used to phase modulate the transmitter in the satellite. All the ground stations receive the transmitted signal and select the channels of interest from the recovered baseband, which contains all the channels in use. In this way a number of ground stations can be connected simultaneously. The wideband data mode is used for transmission of information generated by onboard meteorological cameras. Various types of antennas were used on ATS 1 to 5 with the C-band communications experiment (see Table 3-13).

The VHF experiment, which is on ATS 1 and 3, had the primary objective of evaluating communications between ground stations and aircraft. Other objectives were to: demonstrate the collection of meteorological data from remote terminals, communicate with ships, and evaluate the feasibility of a VHF navigation satellite. The VHF equipment on the two satellites is similar. The antenna is an eight-element phased array with a receiver and transmitter for each element, but with a common IF amplifier.

It is possible to operate only four transmitters to conserve prime power, or to equalize the phase shifters to generate a toroidal antenna pattern. On ATS 3 only, it is possible to receive a VHF signal and transmit it with the C-band transmitter.

The millimeter wave experiment on ATS 5 was designed to measure atmospheric effects on propagation. No repeater is included in the satellite. Rather, on both uplinks and downlinks, a carrier is phase-modulated by a sine wave. The modulation index is chosen to equalize power at the carrier and the first two sideband frequencies. Measurements are made at two frequencies, one for the uplink and the other for the downlink.

These measurements provide data on absorption, refraction, and fading characteristics. Use of the modulated sidebands provides data on the coherence properties of the atmosphere.

The L-band (1550/1650-MHz) equipment on ATS 5 has a design similar to the C-band (4/6-GHz) communications equipment on all five ATS. Its purpose is to investigate navigation and traffic control communications for aircraft. For these functions it may be more suitable than VHF where the available bandwidth is limited and propagation variations limit navigation accuracy. The L-band equipment may be operated as a repeater in the frequency translation mode. In the multiple access mode, up to ten single sideband modulated signals are received at L-band and combined into a composite signal that frequency modulates either the L-band or the C-band transmitter. An alternate frequency translation mode uses the C-band receiver and the L-band transmitter. In addition, the transmitter may be modulated by data from onboard experiments.

Of the five ATS launches, three satellites were successfully placed in orbit. ATS 2 and 4 did not achieve the desired orbit because of launch vehicle malfunctions, and few experimental data were obtained. The ATS 2 C-band repeaters operated 12 and 626 hours, and the ATS 4 repeaters operated only 9 and 30 hours. ATS 4 was in orbit only two months. ATS 2 was in orbit over two years, but was deactivated after six months.

The experiments on both ATS 1 and ATS 3 were used extensively after the satellites were in orbit. Through March 1971 the four microwave communication repeaters on these satellites had accumulated about 35,000 hours of use. Tests were run in all modes, and numerous spacecraft parameters were measured. Various tests were run to determine the values of system noise, delay, frequency response, and intermodulation. In general, system performance was satisfactory according to commercial standards. The C-band communications equipment was also used a number of times for international television broadcasts of public interest.

Engineering performance measurements were also performed on the VHF equipment. System performance was evaluated for ground-satellite-aircraft links using equipment installed on several commercial aircraft. The Coast Guard performed tests using several shipborne terminals. In general, the results with both aircraft and ships were fair to good communications, and the quality of the satellite link was usually as good as, or better than, alternate communication links. The VHF equipment was also used for experiments in clock synchronization, navigation, and meteorological data collection and dissemination. Results were varied, often limited by available equipment or satellite design, but the experiments did provide a data base and recommendations for future work. Since April 1971, the VHF repeater of ATS 1 has been used regularly about 20 hours a week as a single channel international communication system called Project PEACESAT (Pan Pacific Education and Communication Experiments by Satellite). PEACESAT provides cultural and emergency communications to about twelve island nations of the Pacific basin. ATS 3 is also providing communication services in the Pacific basin. Both ATS 1 and ATS 3 have degraded in performance in recent years, but both were in use in 1983.

ATS 5 was successfully placed into synchronous orbit. The satellite was to be spinning upon orbital injection and then despun, at which time the gravity gradient stabilization would begin. However, during orbital injection the satellite developed a spin about an axis normal to the intended spin axis. In this orientation the satellite could not be despun. Because of the spinning condition, the satellite antennas point toward the earth only a small portion of each revolution. Hence, the communication experiments have been operated with limited success in a pulsed type of operation synchronized with the periods of correct antenna orientation.

Table 3-12. ATS Characteristics

Satellite[a]	ATS 1 (B)	ATS 2 (A)	ATS 3 (C)	ATS 4(D)	ATS 5 (E)
Cylinder					
Diameter, in.	58	56	58	56	56
Height, in.	54	72	54	72	72
Initial Orbital Weight, lb	775	702	775	670	670
Solar Cells and NiCd Batteries, W initial	175	130	175	130	130
Stabilization	spin	gravity gradient	spin	gravity gradient	gravity gradient
Design Life, yr	3	3	3	3	3
Actual Orbit	synchronous equatorial, 149°W, moved to 164°W in 1982	100 x 6000 nmi	synchronous equatorial, 105°W	130 x 480 nmi	synchronous equatorial, 70°W
Intended Orbit		6000 nmi		synchronous equatorial	
Launch date	7 Dec 1966	6 Apr 1967	5 Nov 1967	10 Aug 1968	12 Aug 1969
Decay date		2 Sep 1969		17 Oct 1968	
Launch Vehicle	Atlas-Agena	Atlas-Agena	Atlas-Agena	Atlas-Centaur	Atlas-Centaur
Experiments					
C-Band Communications	yes	yes	yes	yes	yes
VHF Communications	yes		yes		
Millimeter Wave Propagation					yes
L-Band Communications					yes

[a]Alphabetic designations are used before launch, numeric after.

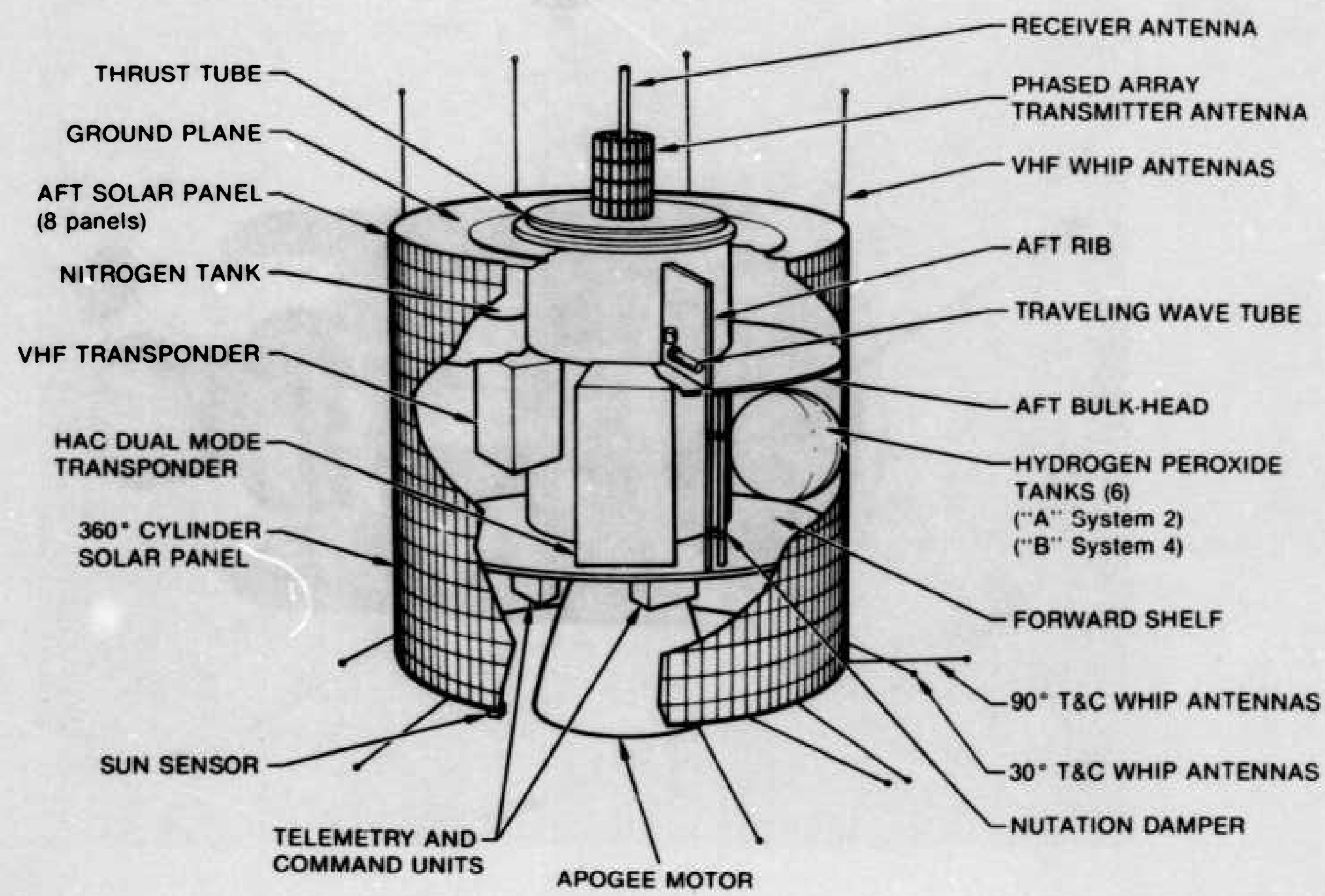


Figure 3-15. ATS 1 Satellite

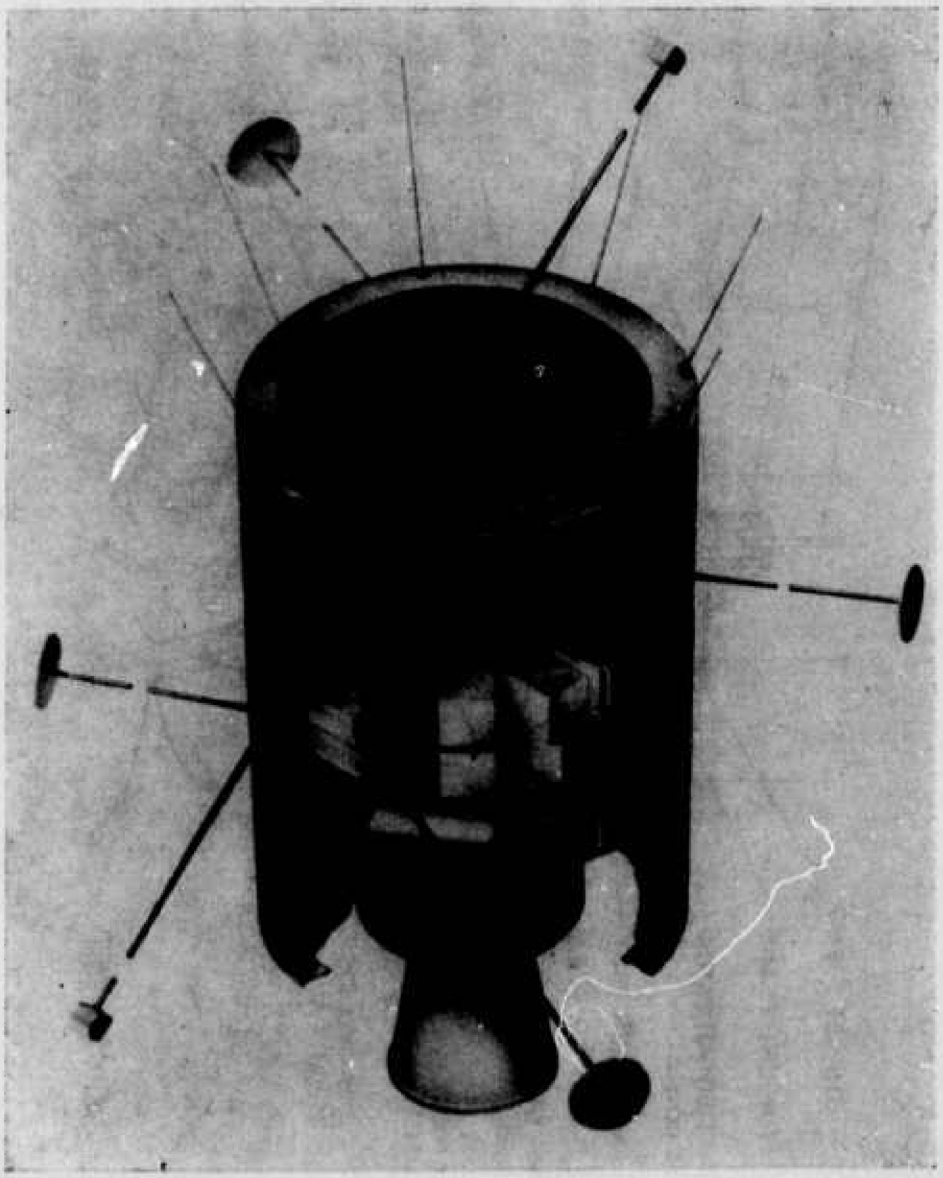


Figure 3-16. ATS 4 Satellite

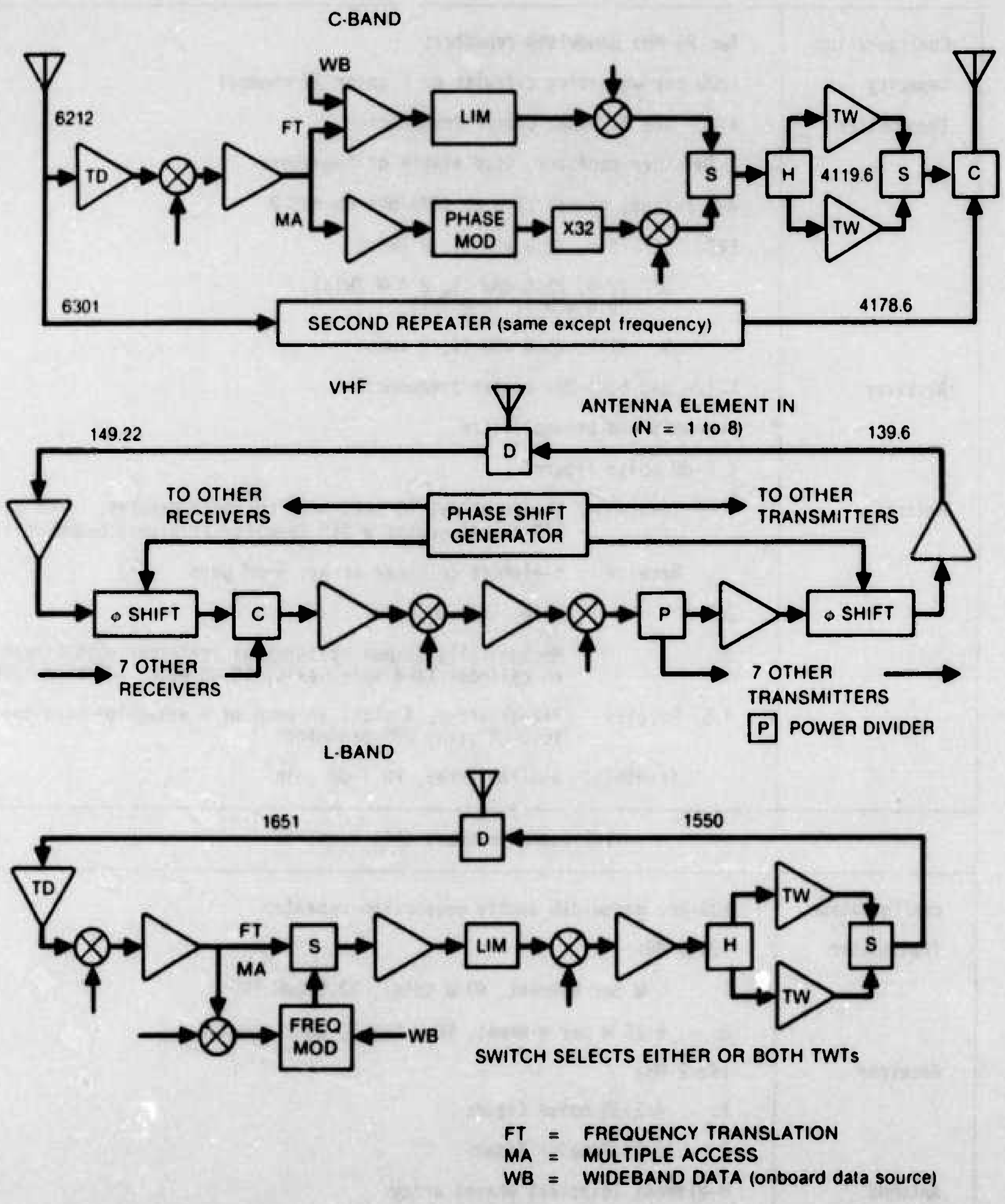


Figure 3-17. ATS Communication Subsystems

Table 3-13. ATS 1 to 5 Experiment Details

C-Band Communications (ATS 1 to 5)	
Configuration	Two 25-MHz bandwidth repeaters
Capacity	1200 one-way voice circuits or 1 color TV channel
Transmitter	4120- and 4179-MHz center frequencies
	2 TWTs per repeater, used singly or together
	4-W output, except 12 W at 4179 MHz on ATS 3
	ERP: 1: 19.5, 22.0 dBW (1, 2 TWTs)
	3: 22.0, 25.0 dBW (1, 2 4-W TWTs), 26.5 dBW (1 12-W TWT)
	5: 22.5, 25.0 dBW (1, 2 TWTs)
Receiver	6212- and 6301-MHz center frequencies
	Tunnel diode preamplifiers
	6.2-dB noise figure
Antenna	1: Transmit — Phased array, 16 sets of 4 colinear dipoles, 14-dB gain, 17° (north-south) x 21° (equatorial plane) beamwidth
	Receive — 6-element colinear array, 6-dB gain
	2: Horn, 10.5-dB gain
	3: Mechanically despun cylindrical reflector with linear feed on cylinder (and spin) axis, 18-dB gain, 17° beamwidth
	4,5: Receive — Planar array, 4 slots in each of 4 waveguide sections, 16.3-dB gain, 23° beamwidth
	Transmit — Similar array, 16.7-dB gain
VHF Communications (ATS 1 and 3)	
Configuration	100-kHz bandwidth double conversion repeater
Transmitter	135.6 MHz
	1: 5 W per element, 40 W total, 22.5-dBW ERP
	3: 6.25 W per element, 50 W total, 25.2-dBW ERP
Receiver	149.2 MHz
	1: 4.5-dB noise figure
	3: 4.0-dB noise figure
Antenna	8-element (dipoles) phased array
	1: 9-dB gain
	3: 10-dB gain

Table 3-13. ATS 1 to 5 Experiment Details

Millimeter Wave Propagation (ATS 5)	
Transmitter	15.3 GHz
	Solid state
	200-mW output
Receiver	31.65 GHz
	15-dB noise figure
Antenna	2 horns (1 each for transmit and receive)
	20^{o} beamwidth, 19-dB gain
Modulation (uplinks and downlinks)	Phase modulation, 1.43 modulation index to provide approximately equal power in carrier and first sidebands
	Modulation frequency: none, 100 kHz, 1 MHz, 10 MHz, or 50 MHz
L-Band Communications (ATS 5)	
Configuration	25-MHz bandwidth repeater
Transmitter	1550-MHz center frequency
	2 TWTs used singly or together
	12 W per TWT, 22.4-dBW ERP (1 TWT), 25.4-dBW ERP (2 TWTs)
Receiver	1651-MHz center frequency
	8-dB noise figure
Antenna	17.2-dB gain

3.10 APPLICATIONS TECHNOLOGY SATELLITE (ATS) 6 (Refs. 50-75)

The ATS 6 satellite was the second generation of the NASA Applications Technology Satellite program.* ATS 1 to 5, launched in 1966 through 1969, constituted the first generation. Eight of the experiments on ATS 6 were communications and propagation studies that extend over a frequency range from 860 MHz to 30 GHz.

ATS 6 consisted of a 30-ft diameter parabolic antenna, an earth-viewing module located at the focus of the parabola, two solar arrays, and the interconnecting structures. The antenna and the solar arrays were deployed after the satellite was in orbit. All the communications experiments were located in a section of the earth-viewing module. Feed horns for the large parabola were mounted on top of the module, and other antennas on the bottom. General satellite characteristics are listed in Table 3-14. Figure 3-18 is a picture of the satellite.

ATS 6 was launched in May 1974. Initially, it was positioned at 94°W longitude where it was used with U.S. ground stations for one year. During June 1975, it was moved to 35°E longitude for the instructional television experiment broadcasts to India. At the same time, the NASA millimeter-wave experiment was used in conjunction with several European ground terminals. After the one-year Indian experiment, in fall 1976, the satellite was slowly returned to the Western Hemisphere. During the transfer period, demonstrations of the social benefits possible with such a satellite were made in 27 countries. ATS 6 was then located at 140°W longitude and used in several experimental programs. It was turned off in the summer of 1979.

*Prior to launch, the satellite was designated ATS F. The program had included a second, very similar satellite called ATS G, but it was canceled for budgetary reasons.

The various communications experiments are described in the following sections. Block diagrams for each part of the ATS 6 communication subsystem are given in Figure 3-19, and details of each experiment are presented in Table 3-15.

The communications equipment on ATS 6 was composed of: four receivers (C-, S-, L-band, and 13/18 GHz); three IF amplifiers; and five transmitters (C-, S-, L-band, 860 MHz, and 20/30 GHz). The 13/18-GHz uplink was downconverted to C-band, amplified, and routed to the C-band transmitter. The other uplinks were amplified and filtered before downconversion to the 150-MHz intermediate frequency. Any receiver (except 13/18-GHz) could have been connected to any one of the three identical IF amplifiers, which could have provided either 12- or 40-MHz bandwidths. The IF outputs could have been connected to any of the transmitters. The transmitters included upconverters, driver amplifiers, and power amplifiers; most of these elements were redundant. The C-band and 20/30 GHz transmitters used traveling wave tubes (TWTs), while the lower frequency transmitters were all transistorized. The primary communication antenna was the 30-ft parabola. In addition, the satellite had a C-band horn, and two small parabolas and a horn for the millimeter-wave experiments. The feed structure for the large reflector included 36 elements to provide efficient performance for the various frequencies and beam patterns used in the communications experiments. Figure 3-20 shows the arrangement of the feed elements on the top surface of the earth-viewing module.

The position location and aircraft communication experiment (PLACE) was an extension of similar experiments conducted at ATS 1, 3, and 5. Like ATS 5, ATS 6 used frequencies around 1550 and 1650 MHz (L-band) for transmissions to and from aircraft. Both voice and digital data transmissions and a four-tone ranging system for aircraft position determination were part of the experimental program. The system was configured to allow multiple access voice from 100 aircraft in 10-kHz channels. Initially, three ground terminals were used to simulate aircraft, with later experiments involving actual aircraft. The ranging signal operation had a transmission to all

aircraft, with a coded data channel to designate one aircraft at a time to return the signal. All frequencies were coherently related to the ground station transmitter frequency so that range rate could be determined as well as range. Experiments included multiple aircraft tracking, determination of capacity limitations (ground equipment simulated most of the aircraft), determination of multipath effects, and evaluation of ground and aircraft terminals.

The satellite instructional television experiment (SITE, or sometimes ITV) was a cooperative effort by NASA and the government of India. The basic objectives were to demonstrate the use of satellite television broadcasting for instructional purposes and to evaluate the various techniques and equipment. The television programs were prepared by the Indian government and transmitted at 6 GHz to ATS 6 from one of three ground stations in India. The satellite retransmitted the signals at 860 MHz. The 860-MHz signal was directly received in 2000 villages by community television receivers with simple 10-foot parabolic antennas. The signal was also received by regular television stations and rebroadcast to about 3000 villages in the standard VHF television band. The television signal had two audio channels with different dialects. (Operational systems may have as many as 14 audio channels to cover the major dialects and languages used in India.) The one year of SITE operation provided experience for development of a national television braodcast satellite system being planned by India.

The TRUST experiment (television relay using small terminals) was similar to SITE and used the same equipment in ATS 6. SITE was used in a year-long instructional program with evaluations of that program, whereas the main objectives of TRUST were hardware oriented. System performance was compared with design values, and ionospheric effects on system performance were measured. Considerable emphasis was placed on the small 860-MHz receiver. A program goal was to develop a terminal that would cost less than $200 in large volume production.

The health/education experiment (formerly the educational TV experiment) was used to test satellite distribution of educational and medical programs. The educational programs were primarily for children, and the medical programs covered both professional education and consultation and general health care. The receiving terminals for the experiment were in areas where present television services are limited because of either geographical (Rocky Mountain states, Alaska) or social factors (Appalachia). Two separate television channels could have been transmitted by ATS 6 using separate antenna beams (produced by two feed horns and the 30-ft reflector). Since a one-deg beamwidth was used, transmission to the varous geographic areas occured at different times. The transmissions from ATS 6 were at 2570 and 2670 MHz (S-band). Some of the receiving terminals were equipped to provide an S-band return link through ATS 6.

In the tracking and data relay satellite experiment, ATS 6 was used to relay commands and tracking signals to, and data and tracking signals from, GEOS-3 and Nimbus 6. The returned data were compared with data received from the spacecraft at a standard ground terminal. The orbit was computed from the range and range rate data obtained through ATS 6, and the uncertainty of the orbit determination compared with theorectical predictions. ATS 6 used S-band for communications with the spacecraft and C-band for communications with the ground. An array of feed horns under the 30-ft reflector was switched to allow the antenna beam to track the spacecraft along its orbit. The same equipment was also used to provide a communications relay between the ground and an Apollo spacecraft during the Apollo-Soyuz Test Project.

The frequencies from 5925 to 6425 MHz are shared by terrestrial and satellite communication services. The RFI experiment was used to determine the extent of interference between these two services. When the RFI experiment was operating, the entire 500-MHz bandwidth of interest was received by ATS 6 and retransmitted to a ground station. Data processing at the ground station was used to determine the power levels and geographic and frequency distribution of the terrestrial sources of noise. The minimum detectable noise source ERP was 10 dBW, and the frequency resolution was

10 kHz. A portable ground station was used as a tracking beacon for ATS 6 and as a system calibration source.

ATS 6 had two millimeter-wave experiments. The NASA experiment used a C-band uplink and 20- and 30-GHz downlinks, while the Communications Satellite (Comsat) Corporation experiment had 13- and 18-GHz uplinks with a C-band downlink. In the NASA experiments, the 20- and 30-GHz downlinks could have been unmodulated, modulated by an onboard tone generator, or modulated by a communication signal received on the C-band uplink. The continuous wave (CW) propagation tests had sufficient power to accommodate fades as deep as 60 dB, while the communication mode was used with digital data rates up to 40 megabits per second (Mbps). A 4-GHz downlink was used with the millimeter-wave downlinks for comparisons. The objectives of the experiment were to measure the characteristics of the millimeter-wave links and to compare directly measured propagation effects with indirect measurements such as radiometric sky temperature, radar backscatter, and meteorological conditions.

In the Comsat millimeter-wave experiment, 39 unmodulated uplinks were received by ATS 6 and retransmitted to a ground station on a C-band downlink. Fifteen stations scattered throughout the eastern part of the United States (>100 miles separation) each transmitted 13- and 18-GHz uplinks. Ten additional stations transmitting 18-GHz uplinks were placed in groups of three near (<25 miles separation) three dual-frequency stations. The experiment operated on a nearly continuous basis for about one year. The results are useful for determining the required weather margins for future communication links using frequencies near 13 or 18 GHz. Data from the three groups of stations, with smaller separations, can be used to determine attenuation correlation and, hence, the uplink improvement possible with space diversity.

Table 3-14. ATS 6 Satellite Characteristics

Shape, Size	30-ft diameter parabolic reflector, 6.5-ft diameter hub section with copper-coated dacron mesh supported by 48 aluminum ribs Earth-viewing module at antenna focus with experiment sections and support subsystems, 54 x 54 x 65 in. 2 solar arrays (deployed in space), each half a cylinder, 54-in. radius, 94 in. long Maximum height 27 ft 6 in. Maximum span 51 ft 8 in.
Initial Orbital Weight	2970 lb
Power	Solar cells and NiCd batteries 645-W initial maximum 415-W minimum after 5 yr
Stabilization	3-axis-stabilized, 0.1° pointing accuracy Pointing to any location on earth Tracking of low altitude satellite over ±11° from local vertical
Design Life	2 yr (required), 5 yr (goal)
Orbit	Synchronous equatorial; 94°W longitude until Jun 1975, 35°E longitude from Jul 1975 to Jul 1976, 140°W longitude until Jul 1979; moved out of synchronous orbit late 1979 or early 1980
Orbital History	Launched 30 May 1974 Titan IIIC launch vehicle In use until turned off (Jul 1979)
Developed for	NASA
Developed by	Fairchild

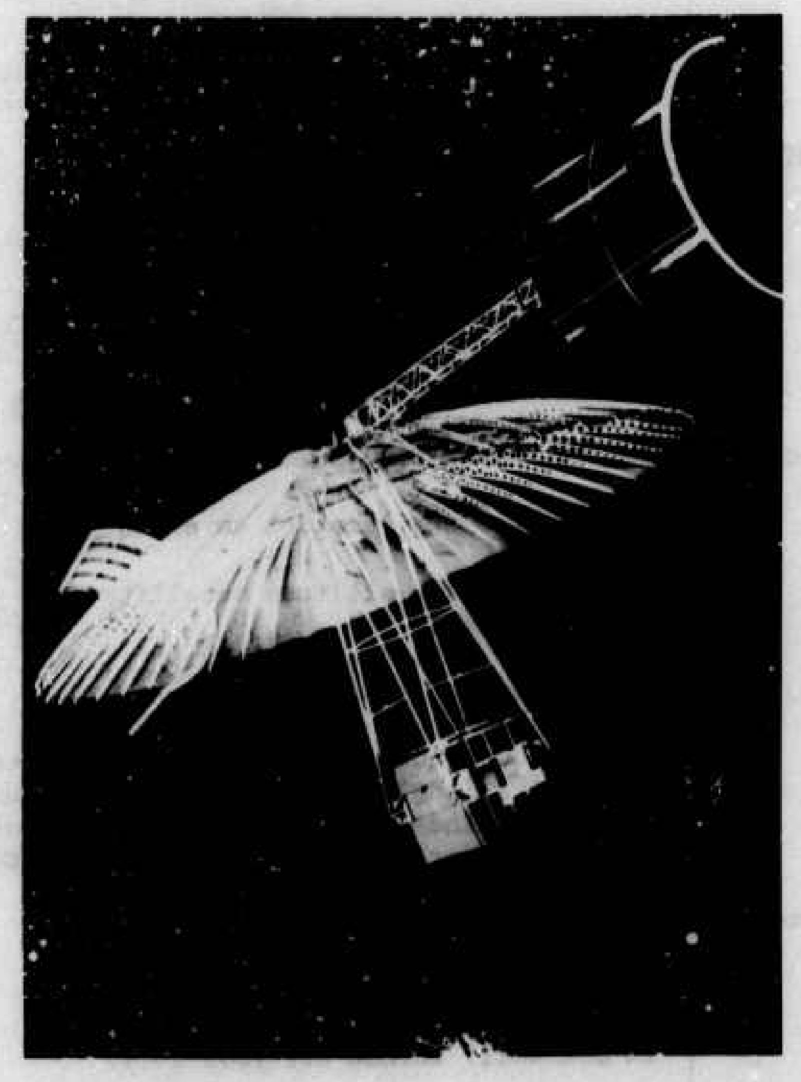


Figure 3-18. ATS 6 Satellite

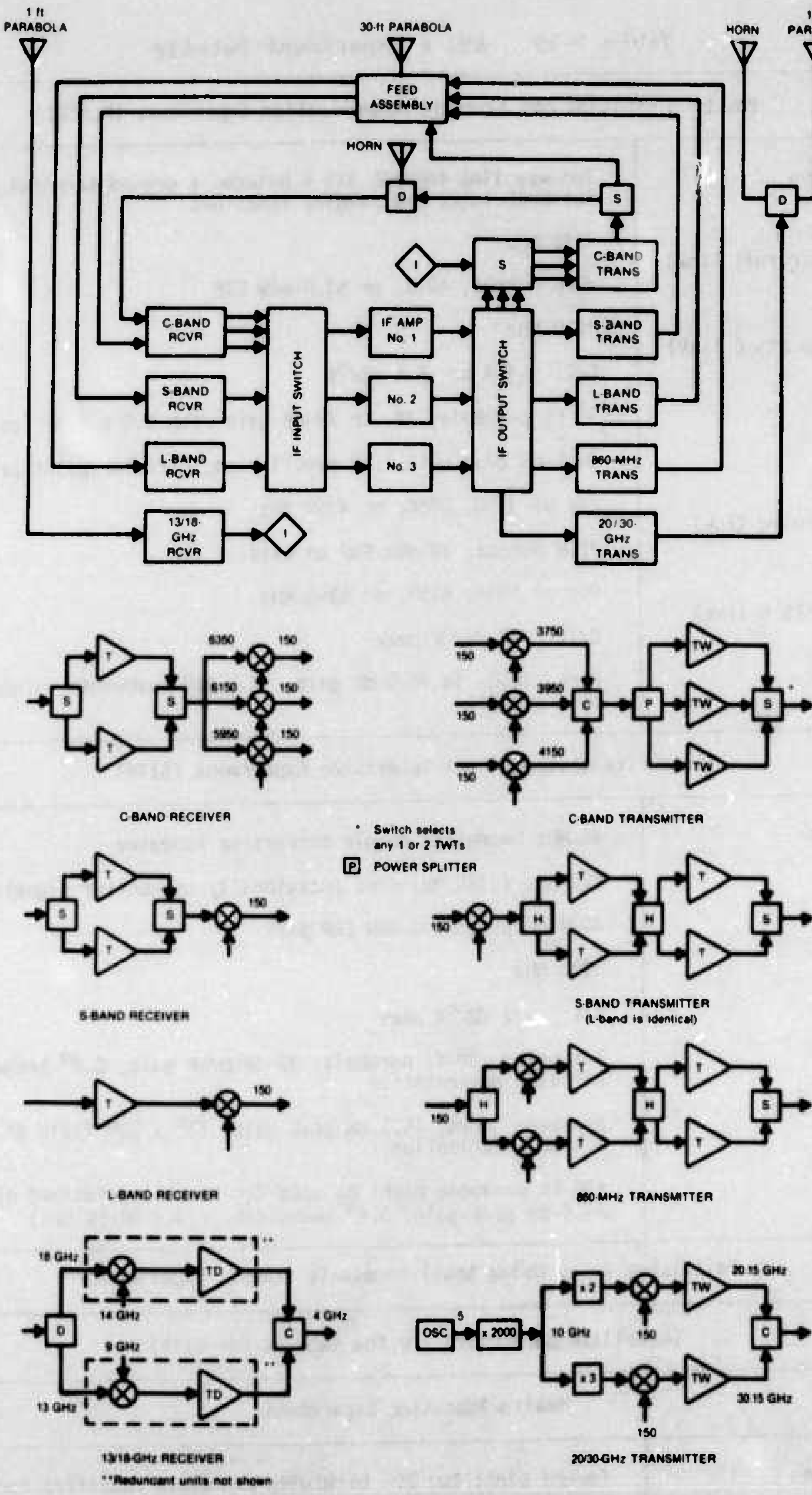


Figure 3-19. ATS 6 Communication Subsystem

Table 3-15. ATS 6 Experiment Details

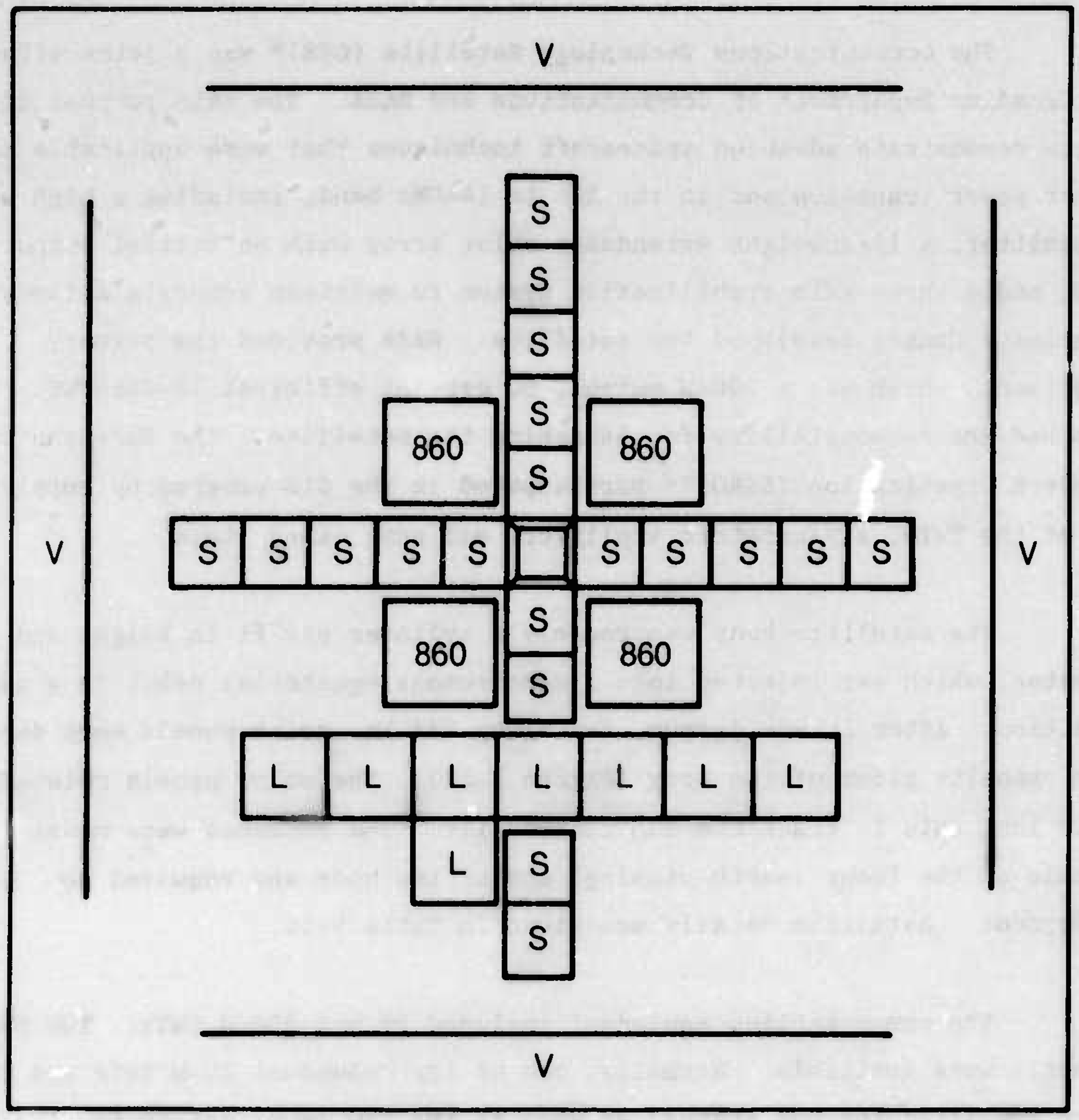
Position Location and Aircraft Communication Experiment (PLACE)	
Configuration	Two-way link through ATS 6 between a ground terminal and aircraft for both voice and ranging functions
Transmitter (ATS 6 to aircraft link)	1550 MHz
	40-W output, 40.3- or 51.0-dBW ERP
Receiver (aircraft to ATS 6 link)	1650 MHz
	G/T: -4.4 or +5.5 dB/°K
Antenna	30-ft parabola, 28- to 29-dB gain with 0.8 x 7.5° fan beam,
	38.5-dB gain with 1.5° pencil beam, circular polarization
Transmitter (ATS 6 to ground link)	One of 3750, 3950, or 4150 MHz
	12-W output, 28-dBW ERP on axis
Receiver (ground to ATS 6 link)	One of 5950, 6150, or 6350 MHz
	G/T: -17 dB/°K peak
Antenna	Horn, 16.3- to 16.5-dB gain, 13 x 20° beamwidth, linear polarization
Satellite Instructional Television Experiment (SITE)	
Configuration	40-MHz bandwidth double conversion repeater
Transmitter	860 MHz (3750 MHz used occasionally to monitor signals)
	80-W output, 51.0-dBW ERP peak
Receiver	5950 MHz
	G/T: -17 dB/°K peak
Antenna	Transmit: 30-ft parabola, 33-dB peak gain, 2.8° beamwidth, circular polarization
	Receive: Horn, 16.3-dB peak gain, 13° x 20° field of view, linear polarization
	(30-ft parabola might be used for receiving instead of horn, 48.4-dB peak gain, 0.4° beamwidth, +13.7 dB/°K G/T)
Television Relay Using Small Terminals (TRUST) Experiment	
(Satellite parameters are the same as for SITE)	
Health/Education Experiment	
Configuration	Foward Link: Two 30- to 40-MHz bandwidth repeaters for 2 FM-TV carriers with sound subcarriers plus separate telephone carriers
	Return Link: For telephone carriers

Table 3-15. ATS 6 Experiment Details (Continued)

Transmitter	2570 and 2670 MHz (also C-band for monitoring)
	15-W output, 53.0-dBW peak ERP
Receiver	5950 MHz
	G/T: -17 dB/°K peak
Antenna	Transmit: 30-ft parabola, 41.5-dB peak gain, 1° beamwidth, circular polarization
	Receive: Horn, 16.3-dB peak gain, 13° x 20° field of view, linear polarization
	(30-ft parabola might be used for receiving instead of horn, 48.4-dB peak gain, 0.4° bandwidth, +13.7 dB/°K G/T)
	Tracking and Data Relay Experiment
Configuration	Two 12- or 40-MHz bandwidth channels
	Two-way link through ATS 6 between ground and a low altitude satellite
Transmitter (ATS 6 to satellite link)	2063 MHz
	20-W output, 48.0-dBW ERP minimum
Receiver (satellite to ATS 6 link)	2253 MHz
	G/T: 7.0 dB/°K minimum
Antenna	30-ft parabola, 36.4-dB gain minimum, 13.2° overall field of view using switched feeds, circular polarization
Transmitter (ATS 6 to ground link)	3753 MHz primary (alternates 3953 or 4153 MHz)
	12-W output, 28.0-dBW ERP peak
Receiver (ground to ATS 6 link)	5938 MHz primary (alternates 6138 or 6338 MHz)
	G/T: -17 dB/°K peak
Antenna	Horn, 16.5-dB transmit gain (peak), 16.3-dB receive, 13 x 20° field of view, linear polarization
	C-Band RFI
Receiver	5925 to 6425 MHz
	G/T: +17.0 dB/°K (30-ft parabola) or -17.0 dB/°K (horn) peak, minimum detectable ground source is 10-dBW ERP
Antenna	30-ft parabola, 48.4-dB gain peak, 0.4° beamwidth, circular or linear polarization
	Horn, 16.3-dB gain peak, 13 x 20° beamwidth, linear polarization

Table 3-5. ATS 6 Experiment Details (Continued)

Millimeter-Wave Experiment (NASA)	
Configuration	Propagation modes: CW or multitone downlinks Communications mode: 40-MHz bandwidth repeater
Transmitter (propagation modes)	20.0 and 30.0 GHz CW: 2-W output, 30-dBW peak ERP Multitone (9 tones): 0.06-W output/tone, 15-dBW peak ERP/tone
Transmitter (communications mode)	20.15 and 30.15 GHz and one of 3750, 3950, or 4150 MHz 20.15 GHz: 2-W output, 40-dBW peak ERP 30.15 GHz: 2-W output, 42-dBW peak ERP C-band: 12-W output, 28-dBW peak ERP
Receiver (communications mode only)	One of 5950, 6150, or 6350 MHz G/T: 13.7 dB/°K (30-ft parabola), -17 dB/°K (horn)
Antenna	Propagation mode: Horn, 27-dB peak gain, $5^{\circ} \times 7^{\circ}$ beamwidth, linear polarization Communication mode: 20.15 GHz: 1.5 ft-parabola, 37-dB gain, 2.4° beamwidth 30.15 GHz: 1.5-ft parabola, 39-dB gain, 1.6° beamwidth C-band transmit: Horn, 16.5-dB gain, $13^{\circ} \times 20^{\circ}$ beamwidth C-band receive: Horn, 16.3-dB gain, $13^{\circ} \times 20^{\circ}$ beamwidth or 30-ft parabola, 48.4-dB gain, 0.4° beamwidth
Millimeter Wave Experiment (Comsat Corporation)	
Configuration	40 unmodulated uplink carriers received and retransmitted to a control ground terminal in a 30-MHz bandwidth
Transmitter	4150 MHz 0.2- to 1.3-mW output per carrier -13 to -21 dBW ERP per carrier
Receiver	15 carriers near 13.19 GHz and 25 carriers near 17.79 GHz 10-dB noise figure
Antenna	Transmit: Horn, 17-dB gain Receive: 1-ft parabola, 26/28-dB peak gain (13/18 GHz), $4 \times 8^{\circ}$ beamwidth, linear polarization



CENTER	C-BAND HORN SURROUNDED BY 4-HORN S-BAND MONOPULSE
S	S-BAND CAVITY BACKED CROSSED DIPOLES
L	L-BAND CAVITY BACKED CROSSED DIPOLES
860	860-MHz CAVITY BACKED CROSSED DIPOLES
V	VHF (130 to 150 MHz) DIPOLES

Figure 3-20. Feed Structure for the ATS 6 30-ft Reflector

3.11 COMMUNICATIONS TECHNOLOGY SATELLITE (Refs 76-94)

The Communications Technology Satellite (CTS)* was a joint effort of the Canadian Department of Communications and NASA. The main purpose of CTS was to demonstrate advanced spacecraft techniques that were applicable to higher power transmissions in the 12- to 14-GHz band, including a high power transmitter, a lightweight extendable solar array with an initial output above 1 kW, and a three-axis stabilization system to maintain accurate antenna pointing. Canada developed the satellite. NASA provided the primary experiment, which was a 200-W output, 50 percent efficient 12-GHz TWT. NASA also had the responsibility for launching the satellite. The European Space Research Organization (ESRO)** participated in the CTS program by supplying one of the TWTs, a parametric amplifier, and some other items.

The satellite body was roughly a cylinder six ft in height and diameter, which was injected into a synchronous equatorial orbit in a spinning condition. After it was despun, two 51-by 244-in. solar panels were deployed from opposite sides of the body (Figure 3-21). The solar panels rotated about their long axis to track the sun continually. The antennas were mounted on gimbals on the front (earth-viewing) end of the body and required no deployment. Satellite details are given in Table 3-16.

The communication equipment included 20-and 200-W TWTs. Two 85-MHz channels were available. Normally, one of the redundant 20-W TWTs was the power amplifier for one channel as well as the low level driver for the 200-W TWT on the second channel. In a backup mode, the 200-W TWT was bypassed and the output of the 20-W TWT was divided between the two channels. Some characteristics of the 200-W TWT, as demonstrated during the first six months in orbit are:

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*Formerly also known as Cooperative Applications Satellite C (CAS-C).
**Now known as ESA (European Space Agency).

a. Construction: coupled cavity, multistage depressed collector, conduction cooling.

b. Radio Frequency (RF) output at saturation: 200-W CW minimum over the operating band, 240-W peak, >30-dB gain, 3-dB bandwidth $\geq$85 MHz.

c. Center Frequency: 12.080 GHz.

d. Efficiency: 45 percent at 224-W output (including power supply).

The CTS had redundant receivers, one with a tunnel diode preamplifier and the other with a parametric amplifier. Both receiver chains were single conversion and had a tunnel diode amplifier (TDA) following the mixer. The receivers fed redundant field effect transistor amplifiers that provided the input signals for the TWTs. Figure 3-22 is a block diagram of the communications equipment.

The CTS had two narrowbeam antennas, one directed toward a control terminal and the other toward remote terminals. The two channels were used for two-way communications. The high power TWT was used for transmission to the remote terminals that used relatively small antennas.

Canada, NASA, and other U.S. Government agencies began to conduct communication experiments with the CTS following its launch on January 19, 1976. Canada had its control terminal at Ottawa and remote terminals in the north. The capability of the CTS allowed the remote terminals to be relatively small, as indicated by the characteristics listed in Table 3-17. The CTS could support several simultaneous links with these terminals. For example, the eight-ft terminal listed in Table 3-17 could receive a television signal transmitted with only a quarter of the total CTS power. In May 1976 the CTS was renamed Hermes in Canada. By mid-1978, 32 experimental programs had been completed or were in progress and seven more were planned. These experiments were in the fields of propogation, communications engineering, television broadcasting, education, medicine, government, and community affairs. The operational viability of many of these projects is being studied further using the 12- and 14-GHz channels on Anik B (see Section 7.1.2). CTS was used until November 1979, at which time it was turned off.

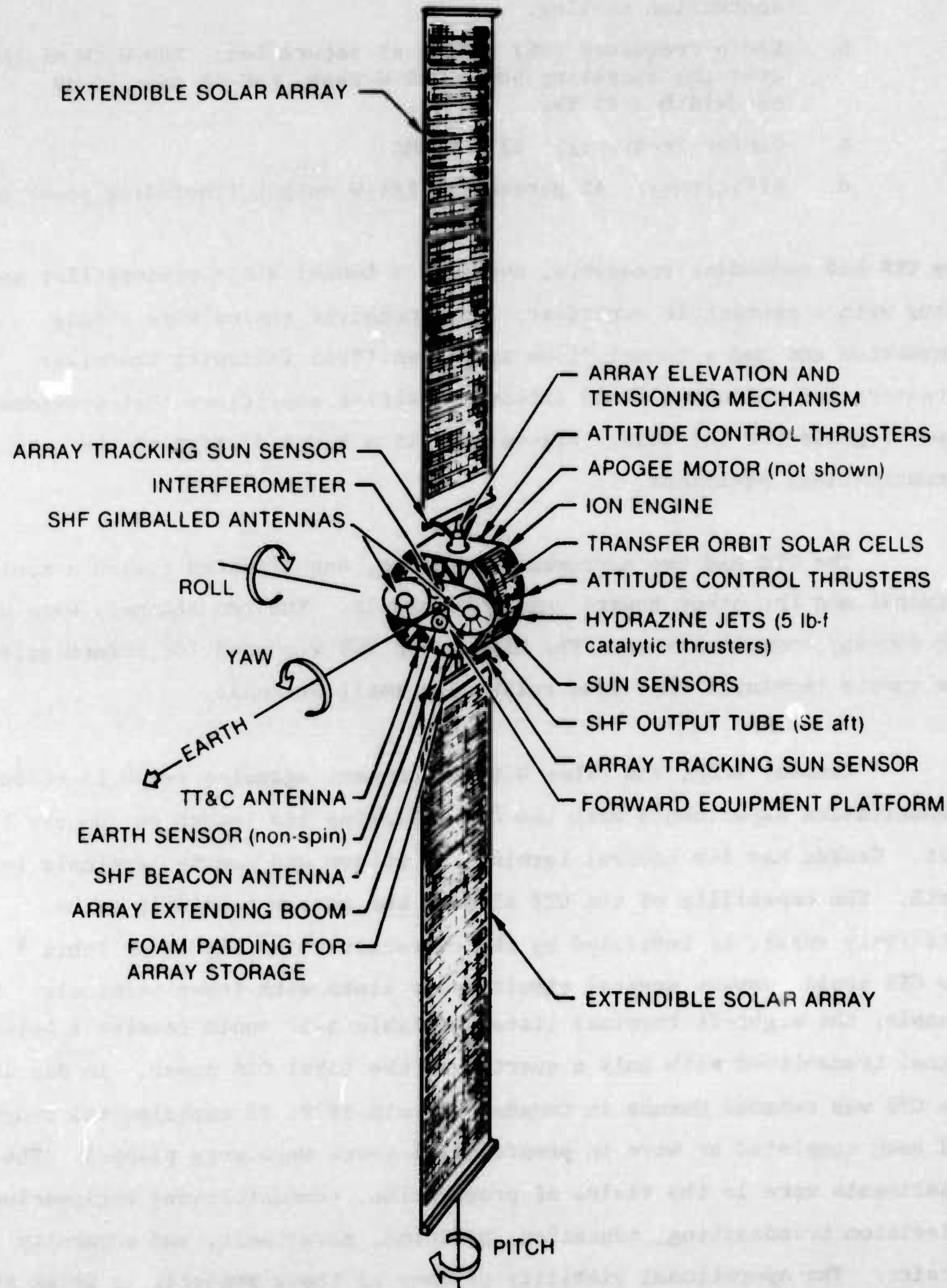

Figure 3-21. CTS Satellite

Table 3-16. CTS Details

Satellite	Body 72-in. diameter, 74 in. high with 2 solar arrays 51 in. wide, 20 ft 4 in. long; total satellite span 52 ft 9 in.
	738 lb in orbit, beginning of life
	Sun tracking solar array and NiCd batteries, 1360 W initially, ~930 W minimum during last year (1979)
	3-axis stabilization, $\pm 0.1^{\circ}$ about pitch (north-south) and roll (velocity vector) axes, $\pm 1.1^{\circ}$ about yaw (radial) axis
Configuration	Two 85-MHz bandwidth single conversion repeaters
Transmitter	11.843 to 11.928 and 12.038 to 12.123 GHz
	Normal configuration 20-W TWT on low band and 200-W TWT on high band, alternately both bands share the 20-W TWT (at reduced capability)
Receiver	14.010 to 14.095 and 14.205 to 14.290 GHz
	2 preamplifier chains (1 on, 1 standby)
	Noise temperature: ~2000°K with tunnel diode preamplifier
	~1350°K with parametric amplifier
	G/T: 6.4 dB/$^{\circ}$K on-axis with parametric amplifier
Antennas	Two 28-in. diameter antennas, 36.2-dB gain on axis for transmit and receive, 2.5° beamwidth, steerable over $\pm 7.25^{\circ}$, linear polarization
Design Life	2 yr
Orbit	Synchronous equatorial, 116°W longitude, (142° from Jul 1979) $\pm 0.2^{\circ}$E-W stationkeeping, inclination $\leq 0.8^{\circ}$ through mid 1979
Orbital History	Launched 17 Jan 1976
	Delta 2914 launch vehicle
	In use until turned off (Nov 1979)
Developed by	Canadian Department of Communications

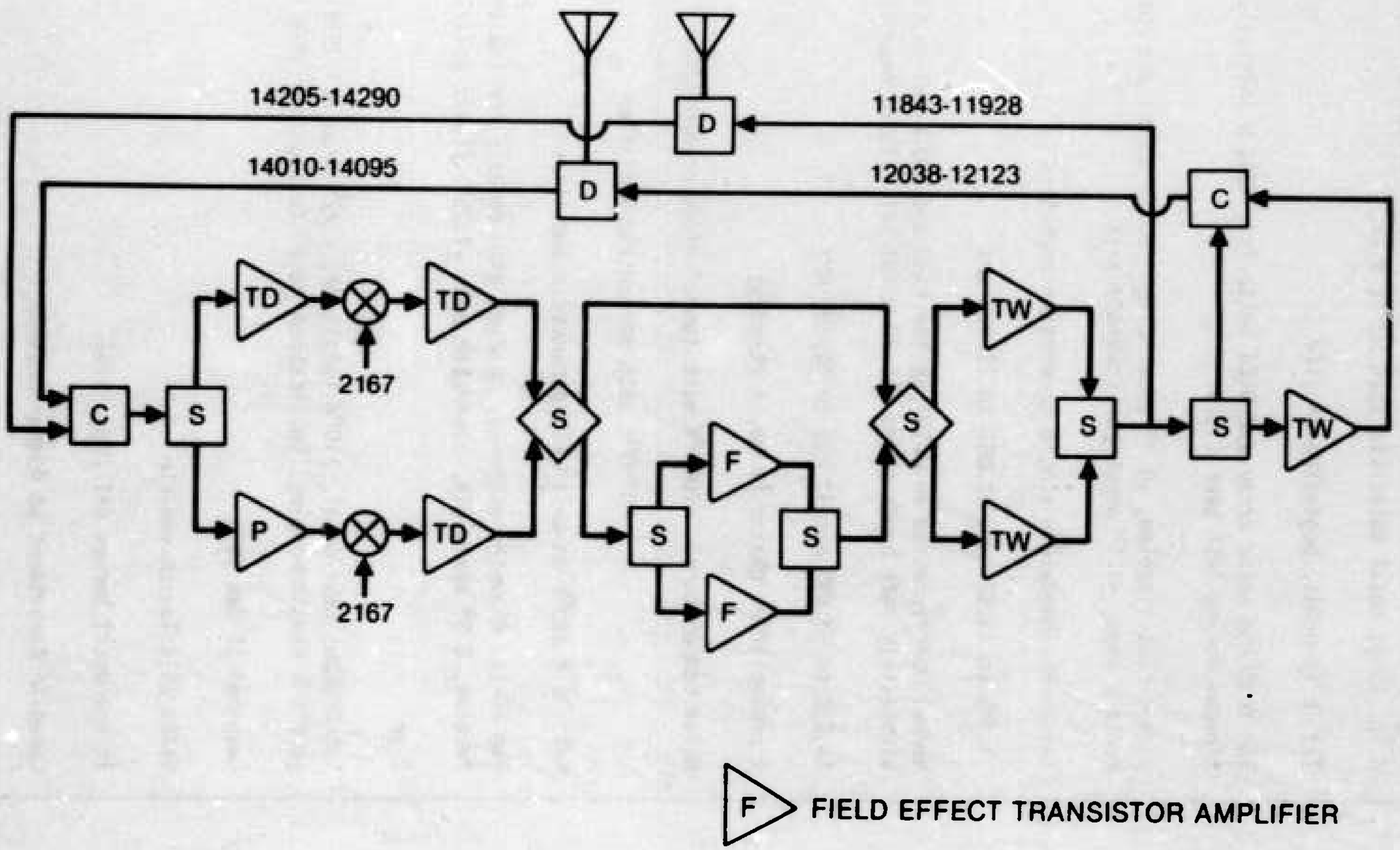

Figure 3-22. CTS Communication Subsystem

Table 3-17. Canadian CTS Ground Terminals

Function	Diameter (ft)	Antenna		Receiver Type and Noise Temperature (^{o}K)	GT ($dB/^{o}K$)	Maximum Transmitter Power (W)
		Peak Gain (dB)	Beamwidth (deg)			
Control Terminal						
Transmit and receive TV and multiplexed voice signals	30	59	0.18	Uncooled paramp, 425	32.9	1000
Remote Terminals						
TV transmission	10	50	0.54	TDA, 1150	19.5	1000
TV reception and two-way voice	8	48	0.67	TDA, 1150	16.5	1
Two-way voice	4	42	1.3	Mixer, 2660	7.8	1
Receive FM sound broadcast	2 equivalent	35	2 x 4	Mixer, 2660	0.8	—

3.12 SIRIO (Refs. 95-106)

The Italian industrial research satellite (Sirio) was developed for use in propagation and communication experiments at 11.6 and 17.4 GHz.* A large part of the Italian aerospace industry participated in construction of the satellite under direction of the Italian National Research Council (CNR). Three ground stations in Italy plus stations in other European countries participate in the Sirio experiments.

The satellite has a cylindrical body that is spin-stabilized, with a despun antenna on one end. All the equipment is mounted on an internal platform. The payload is primarily for support of the three primary experiments: propagation, narrowband communications, and wideband communications. Secondary experiments are for measurements of the natural environment at synchronous altitude. Figure 3-23 is a drawing of the satellite, and Figure 3-24 is a block diagram of the communications subsystem.

In the propagation experiment, the 17.4-GHz uplink is amplitude modulated at 386 MHz to produce two sidetones 772 MHz apart. In the satellite, they are converted to about 386 MHz with a separation of 20 kHz, and a calibrated reference signal is inserted between them. (See the spectral diagram in Figure 3-25). This combined signal is further converted to 266 MHz and used to amplitude modulate the 11.6-GHz downlink carrier. The downlink carrier amplitude is controlled to provide a reference level. This combination of uplinks and downlinks allows all measurements to be performed on the ground. The measurements made are absolute attenuation at 11.6 and 17.4 GHz, and relative attenuation and phase delay over frequency intervals of 772 MHz and 532 MHz. In addition, multiple ground receivers are used to measure space diversity improvement. Space diversity on the uplink is achieved by having two sidetones transmitted from different locations.

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*These frequencies were chosen prior to the 1971 World Administrative Radio Conference and, therefore, do not exactly coincide with the satellite communication frequency bands defined at the conference.

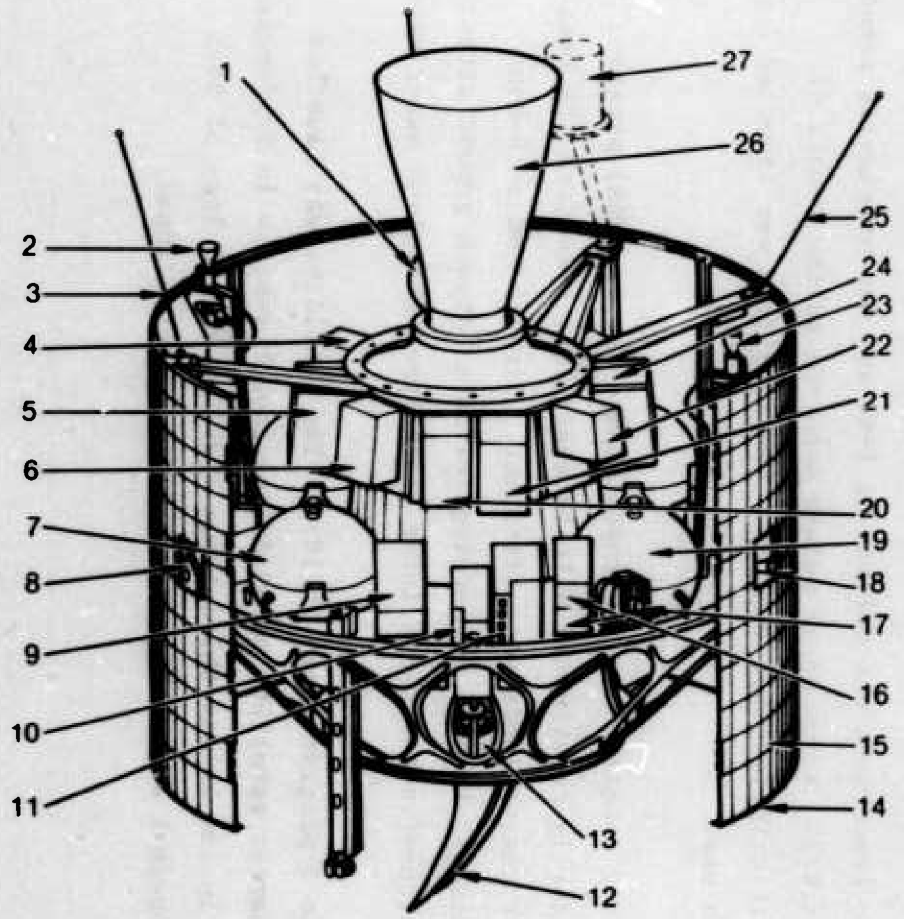
In the narrowband communication mode, up to 12 biphase modulated carriers are transmitted to the satellite using frequency division multiplexing. The data rate on each carrier is 70 kbps, and the satellite bandwidth is 2.5 MHz. In the satellite, the combined signal is amplified at IF and then used to modulate the downlink carrier. The wideband communication mode is similar, except that the satellite bandwidth is 35 MHz. The uplink transmission is a single television channel. Some consideration is being given to using high rate digital data transmissions in this mode also.

The satellite may be operated in any one of three modes. The satellite equipment is common for all the modes except for portions of the IF section. The transmitter output power is 10 W from either of two TWTs. Other details of the equipment are given in Table 3-18.

The Sirio experiment was defined in 1968 and was originally scheduled to be launched in 1972. A number of delays occurred as the result of technical and political/financial reasons. The satellite was launched August 25, 1977 and is in use.

The Sirio 2 satellite is a European Space Agency (ESA) program. The satellite was primarily constructed with hardware left over from the basic Sirio program, but the payloads were different. Sirio 2 had an S-band transponder for distribution of meteorological data between ground sites, and a detector and retroreflector for a laser clock synchronization experiment.

The Sirio 2 program began in 1978. The satellite was launched together with a Marecs satellite on an Ariane launch vehicle in September 1982. A failure in the Ariane third-stage resulted in the loss of both satellites. At present a replacement satellite is not planned.



KEY
1 ETA-BETA EXPERIMENT
2 AXIAL AUXILIARY ENGINE NOZZLE
3 VHF ANTENNA
4 ELECTRONIC TEMPERATURE BRIDGES
5 TELEMETRY ENCODER
6 ATTITUDE CONTROL LOGIC
7 HYDRAZINE FUEL TANK
8 COLATITUDINAL SENSOR
9 DIGITAL COUNTER
10 MEDIUM ENERGY SENSOR
11 HIGH ENERGY SENSOR
12 SHF EXPERIMENTAL ANTENNA
13 SHF TRANSPONDER
14 SATELLITE HOUSING
15 SOLAR CELLS
16 COMMAND DECODER
17 LEVEL SENSOR
18 RADIAL AUXILIARY ENGINE NOZZLE
19 HYDRAZINE TANK
20 POWER CONVERTER
21 ANALOG/DIGITAL CONVERTER
22 ELECTRONIC TEMPERATURE BRIDGES
23 AXIAL AUXILIARY ENGINE NOZZLE
24 TELEMETRY ENCODER
25 VHF ANTENNA
26 APOGEE MOTOR
27 MAGNETOMETER

Figure 3-23. Sirio Satellite

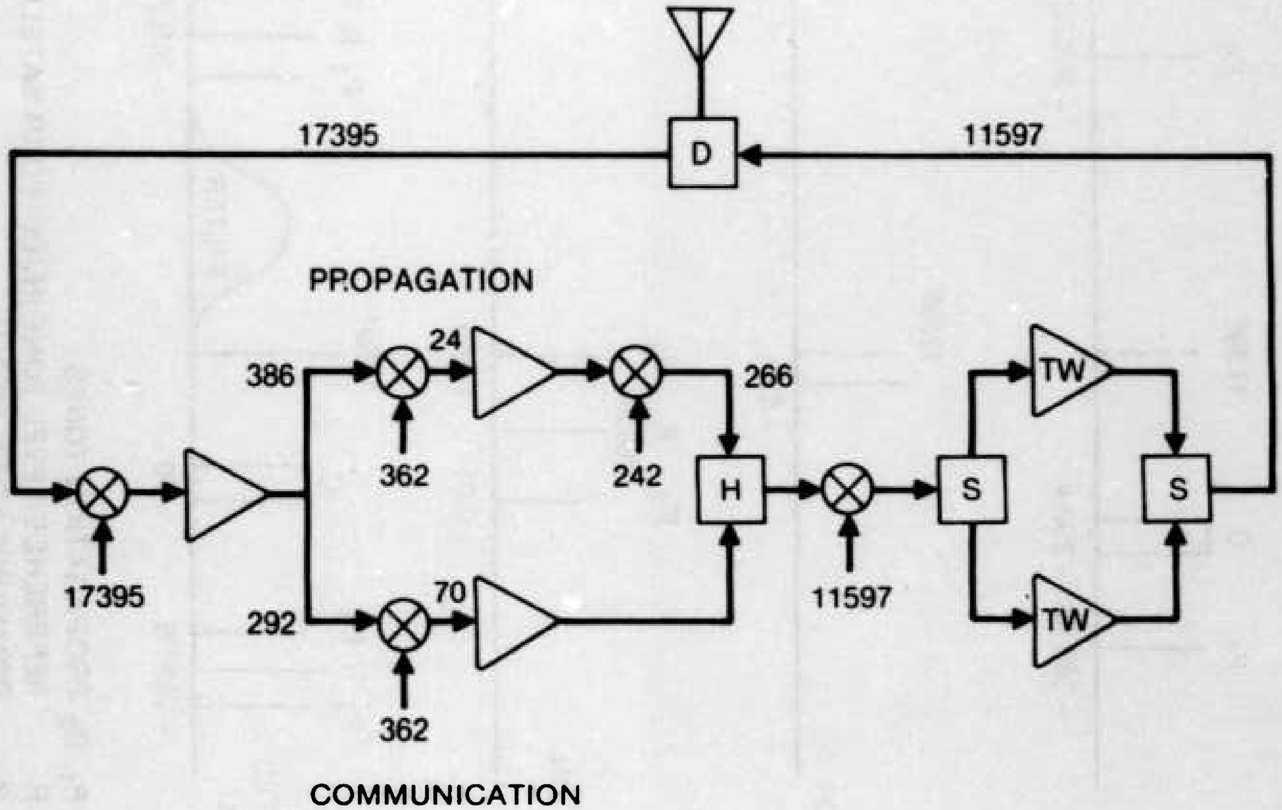


Figure 3-24. Sirio Communication Subsystem

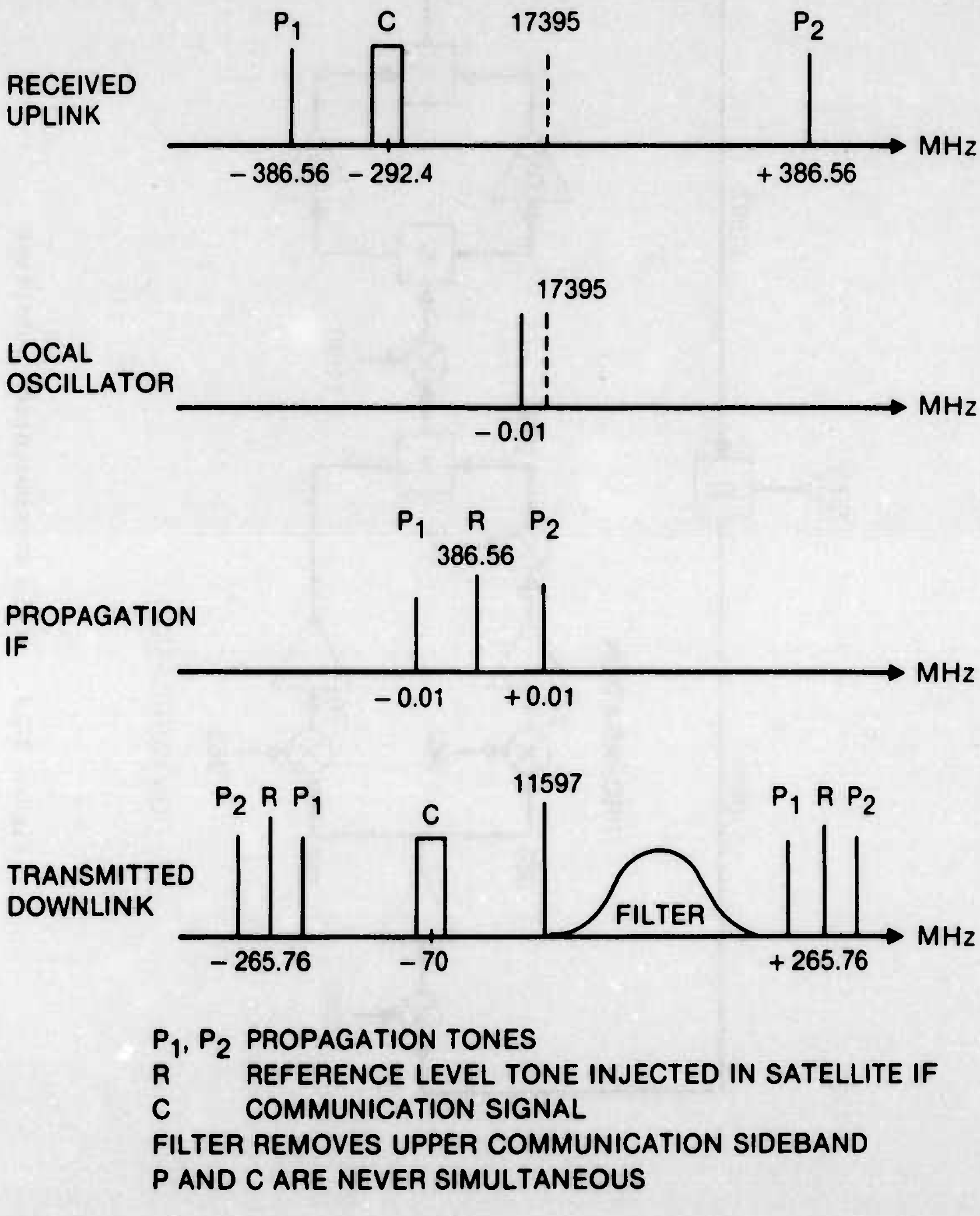


Figure 3-25. RF Spectra in the Sirio Satellite

Table 3-18. Sirio Details

Satellite	Cylinder, 56-in. diameter, 34 in. high, overall height 78 in. 480 lb in orbit, beginning of life Solar cells, 135 W beginning of life, 100 W minimum after 2 yr Spin-stabilized, 90 rpm
Configuration	Communication experiment: 2.5-MHz bandwidth repeater with up to twelve 70-kbps carriers, or 35-MHz bandwidth repeater with 1 TV channel Propagation experiment: 40-kHz bandwidth repeater
Transmitter	11.597 GHz 10-W output (saturated) TWT (1 on, 1 standby) ERP: Propagation mode - 16 dBW Narrowband communication - 24 dBW Wideband communication - 26 dBW All at edge of coverage (all 5 dB higher in central 1^o of antenna)
Receiver	17.395 GHz G/T: -16 dB/°K (-10 dB/°K over central $3^o \times 5^o$ of beam)
Antenna	Fixed feed horn with mechanically despun reflector, >22.5/23.5-dB gain on axis (11.6/17.4 GHz), $6^o \times 10^o$ beamwidth (6^o is north-south beamwidth), beam center 6.5^o above equatorial plane, steerable 3.5^o west to 4.5^o east of satellite nadir, circular polarization
Design Life	2 yr
Orbit	Synchronous equatorial, 15°W longitude, later moved to 12°E longitude
Orbital History	Launched 25 Aug 1977 Delta 2313 launch vehicle In use (Jan 1983)
Developed for	CNR (Consiglio Nazionale della Richerche)
Developed by	Italian aerospace industry

3.13 LINCOLN EXPERIMENTAL SATELLITES (LES)-8 AND -9 (Refs. 107-112)

The LES-8 and -9 are the latest in a series of experimental military communication satellites developed by the MIT Lincoln Laboratory. They are operating with a variety of fixed and mobile terminals using both UHF and K-band (36 to 38 GHz) for uplinks and downlinks. A K-band crosslink between LES-8 and LES-9 is a significant part of the program. The communications electronics are all solid state. Two K-band receivers and transmitters are on each satellite, one used with a horn antenna and the other with an 18-in. parabolic reflector. The paraboloid works with a steerable flat plate and a five-horn feed to provide a narrowbeam tracking antenna. This antenna is normally used for crosslink communications, but can also be used for uplink/downlink traffic. The satellites can acquire the crosslink with initial pointing uncertainties greater than ± 1 deg and maintain tracking to better than 0.1 deg at typical signal levels. The horn antenna is fixed and is used only for uplinks and downlinks. The K-band transmitters use parallel Impatt diode amplifiers to produce an output power of 0.5 W. The crosslink bit rate is either 10 or 100 kbps, using phase shift keying (PSK) modulation. THe K-band uplinks use both eight-tone frequency shift keying (FSK) and DQPSK; the K-band downlinks use DPSK. All UHF transmissions use eight-tone FSK. For transmissions involving UHF links, which are primarily for relatively simple mobile terminals, the basic data rate is 75 bps. The K-band links can handle selected information rates up to 19,200 bps, which is adequate for computer data or digitized voice. Except for an optional UHF frequency translation mode with a bandwidth of 500 kHz, all received uplinks are translated to intermediate frequencies and then demodulated. All signal routing is controlled by switches set by commands from the ground. The basic routings available are shown in the block diagram in Figure 3-26.

LES-8 and -9 are practically identical. Most of the electronic subsystems are contained in the satellite body, which is 46 in. long and about 44 in. across. The two radioisotope thermoelectric generators (RTGs) are mounted one upon the other on the back end of the satellite body. These RTGs provide all the electrical power used by the satellite; no solar cells are

used. The UHF antenna is also attached to the back end of the satellite body. The K-band antennas and some electronics, plus earth sensors, are mounted on the front end. The overall length of the satellite is about 10 ft. All of these items are shown in Figure 3-27. The satellite is three-axis-stabilized by a gimbaled momentum wheel and 10 gas thrusters. Additional details are provided in Table 3-19.

LES-8 and -9 were launched together on a Titan IIIC booster on March 14, 1976. The initial tests showed that all important communications parameter values were in good agreement with the prelaunch measurements. Since then, the satellites have been exercised in a variety of modes, both for detailed performance measurements and for functionally oriented demonstrations to prove the operability of the various links. These tests have involved ground and mobile terminals developed by Lincoln Laboratory, the Air Force, and the Navy. The test results have all been satisfactory and have shown that the LES-8 and -9 communications features are operationally useful. The satellites were still being used in 1983, and are expected to give several more years of service.

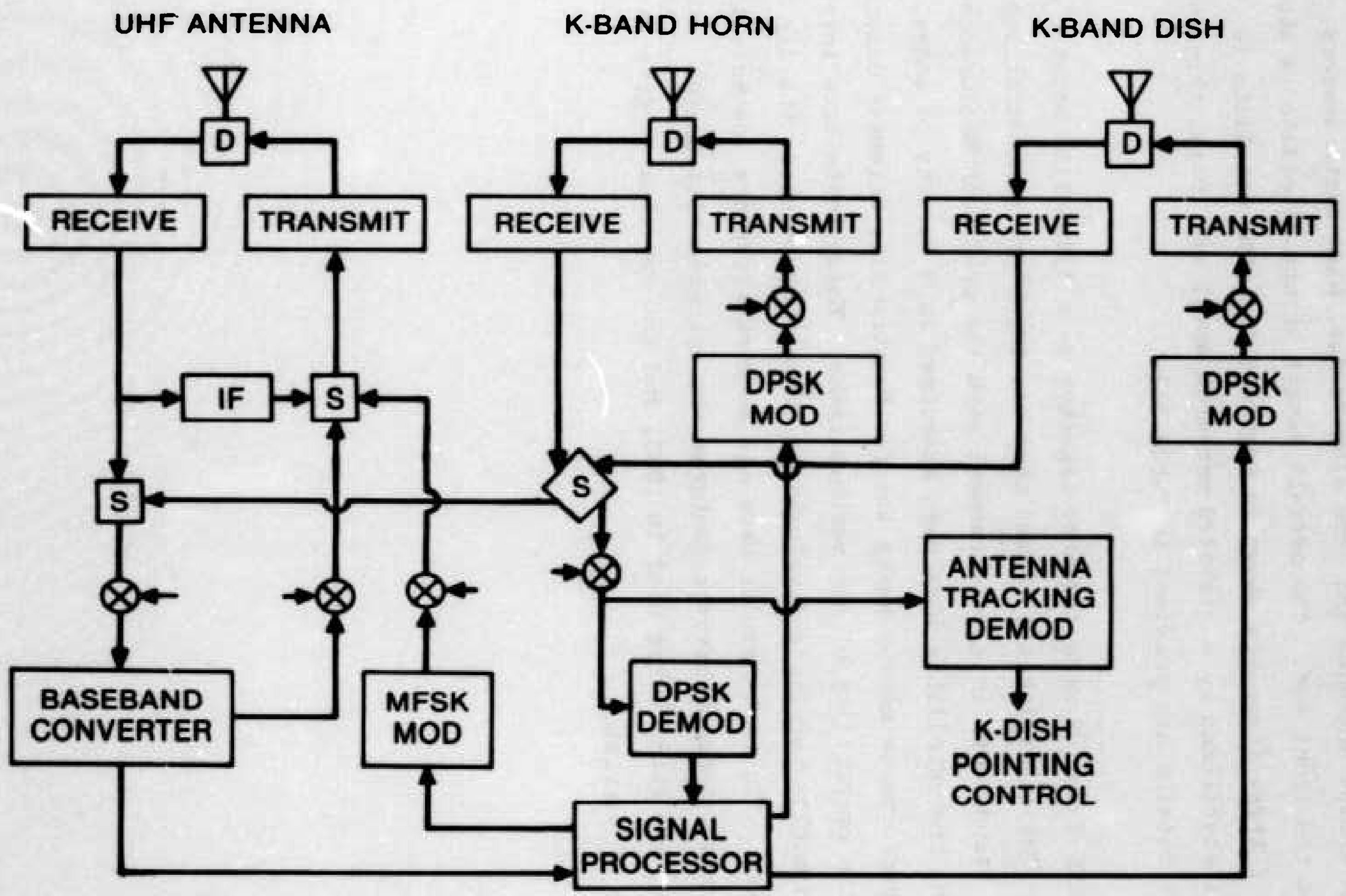


Figure 3-26. LES-8 and -9 Communication Subsystem

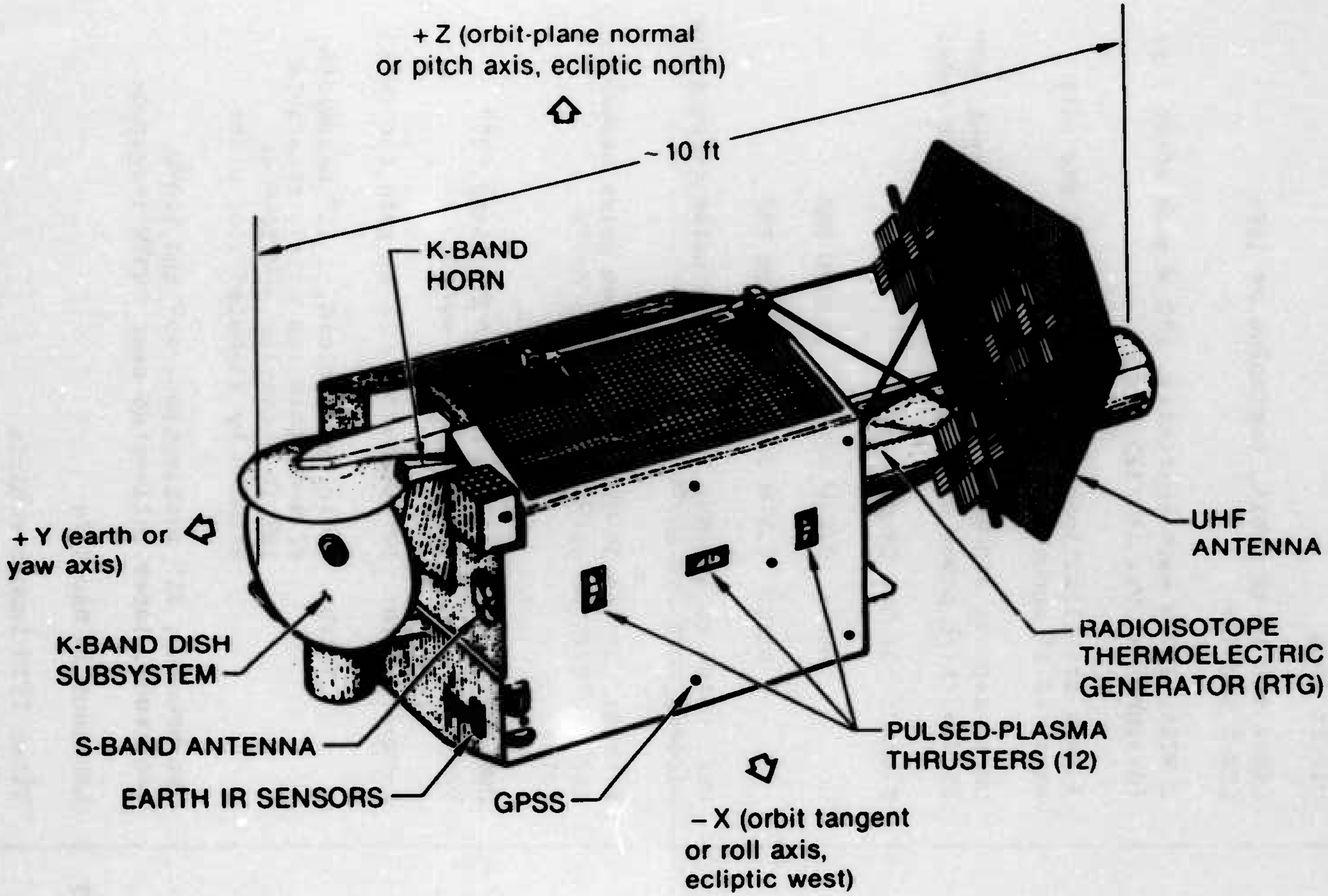


Figure 3-27. LES-9 Satellite

Table 3-19. LES-8 and -9 Details

Satellite	~10 ft long LES-9 948 lb in orbit, beginning of life LES-8 similar 2 RTGs, 152 W each initially, 130 W each after 5 yr (design goal was 145/125 W) 3-axis stabilization, $\pm 0.1^{\circ}$ about pitch and roll axes, $\pm 0.6^{\circ}$ about yaw axis
Transmitter	UHF: 240- to 400-MHz band, 32-W or 8-W output, ERP 25 dBW (high power mode) or 18 dBW (low power mode) K-band: 36- to 38-GHz band Horn: 0.5-W output, 21-dBW ERP Dish: 0.5-W output, 39-dBW ERP
Receiver	UHF: 240- to 400-MHz band, system noise temperature ~1000°K, G/T -20 dB/°K K-band: 36- to 38-GHz band, system noise temperature 1400°K, G/T $\geq$-8 dB/°K (horn), $\geq$10 dB/°K (dish)
Antenna	UHF: 3 crossed dipoles on a ground plane, 35° beamwidth, ~8 dB gain (edge of earth) K-band: Horn: 10° beamwidth, 24-dB gain (on axis) Dish: 18-in. paraboloid, 1.15° beamwidth, 42.6-dB gain (on axis), steerable 10° in elevation and 104° in azimuth by gimbaled flat plane
Orbit	Synchronous, 25° inclination, 40° and 110°W longitude, later collocated near 109°W longitude
Orbital History	Launched 14 Mar 1976 Titan IIIC launch vehicle In use (1983)
Developed by	MIT Lincoln Laboratory

3.14 ADVANCED COMMUNICATIONS TECHNOLOGY SATELLITE (ACTS) (Refs. 113-116)

In 1973 NASA greatly reduced its efforts in communications technology, primarily because of budget restrictions. Private industry supported some developments with short term (e.g., a few years) potential for commercial success. However, private industry could not support the higher risk, higher potential developments which require about a decade to bring to commercial usefulness. Because of this, and with urgings from many directions, NASA was able to resume its support of communications technology in 1978.

The major item in the new program is a high capacity domestic communications satellite using the 30- and 20-GHz bands. This became known as the 30/20 GHz program. Market analyses and system studies were done first. Then in 1980, several hardware developments were started. These include a multibeam antenna with both fixed and scanned beams, a baseband processor, an IF switch matrix, a TWTA, and a low noise receiver. The completion dates for these developments fall between late 1982 and mid 1984.

In the spring of 1983 NASA opened bidding for construction and orbital support for a single Advanced Communications Technology Satellite (ACTS)[a]. The ACTS will incorporate the results of the hardware developments, and demonstrate all the objectives of the 30/20 GHz program. However, in size it will be much smaller than an eventual operational satellite. For example, ACTS will have three antenna beams and a 3 x 3 IF switch whereas these values would be 20 or more in an operational satellite. Besides the multibeam antenna and IF switch, critical technology items include a dual power level TWT and a baseband processor able to demodulate, sort, store, and route messages.

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[a]Through the first half of 1984 the government was reconsidering the ACTS program because of commercial initiatives in 30/20 GHz satellites. By June no decision was reached.

The ACTS is to combine the new communications hardware with an existing spacecraft bus. NASA requires a two-year life for the ACTS payload. The contractor may operate other payloads on the same bus and gains control of the ACTS payload after the two years. NASA expected to award a contract in December 1983 and launch the satellite in the latter part of 1988.

4. INTERNATIONAL SATELLITES

When satellite technology matured enough to be used for regular public communications, satellites were quickly brought into international service. These satellites were developed and owned by Intelsat, an international organization with communication agencies of many nations as members. Over the past 10 years, Intelsat has brought five generations of satellites into service, and development of the sixth generation is in progress. Each of these satellites is described in this section. Since the Intelsat system represents an outstanding, continually growing example of the commercial application of space technology, an overall description of the system is given at the end of the section.

For many years, international organizations have supervised communication services provided to ships and airplanes. Satellites have been extensively studied for use in these services, and a new international organization, Inmarsat, was formed in 1979. The Inmarsat system is now in operation and is described in this section.

4.1 EARLY BIRD (INTELSAT I) (Refs. 117-125)

In August 1964 the International Telecommunication Satellite Consortium (now known as Intelsat) was formed. The purpose of Intelsat was the production, ownership, management, and use of a global communication satellite system. The feasibility of satellite communications had already been proven, and Intelsat decided to launch a satellite to gain information in four areas:

a. Rain margins required at ground stations.

b. Reaction of telephone users to the transmission delay.

c. Long-term operation of the stationkeeping control valves.

d. Applicability of communication satellites for commercial telephone use.

The satellite was basically experimental to provide some results in these areas of uncertainty. If the results were favorable, the satellite would be put into operational use. Because of the success of Syncom, Intelsat decided to use a satellite of similar design. However, at the same time, three design studies were initiated, covering the three possible orbital modes for a fully operational system. The three choices were: randomly spaced medium altitude satellites, gravity-gradient-stabilized medium altitude satellites with controlled phasing, and larger satellites in synchronous equatorial orbits.

The Early Bird design (Figure 4-1) basically followed the Syncom 3 design. The bandwidth and radiated power were increased to provide better service, including two-way television. Larger solar cell panels were used, increasing the satellite height. Since the satellite was to be used for transmission between North America and Europe, the antenna pattern was shaped to service the northern hemisphere. Maximum gain occurred at 45°N latitude, rather than at the equator. The satellite had two independent repeaters, one for transmissions from Europe to North America and the other for the opposite direction. Details are given in Table 4-1 and the block diagram of Figure 4-2.

Early Bird (also known as Intelsat I) was launched in April 1965. Extensive tests were conducted using stations in Maine, England, France, and Germany, which had also operated with Telstar and Relay. Noise, intermodulation, and frequency response measurements were made with single and multiple carriers with voice and television signals. Optimal operating points for ground equipment were determined. The tests indicated that operation to commercial standards could be maintained. DoD also conducted limited tests using Early Bird.

Early Bird was initiated into regular commercial service in June 1965 and operated regularly until January 1969. In July and August 1969, it was used again during a temporary outage of Intelsat IIIB.

Figure 4-1. Early Bird Satellite

Table 4-1. Early Bird Details

Satellite	Cylinder, 28-in. diameter, 23 in. high
	85 lb in orbit, beginning of life
	Solar cells, 45-W maximum, 33-W minimum after 3 yr (NiCd batteries are not used by the communication subsystem)
	Spin-stabilized
Configuration	Two 25-MHz bandwidth double conversion repeaters
Capacity	240 two-way voice circuits or 1 two-way television circuit
Transmitter	4081 MHz to U.S., 4161 MHz to Europe
	2 TWTs (1 on, 1 standby)
	6-W output, 10- to 11-dBW ERP per repeater
Receiver	6390 MHz from U.S., 6301 MHz from Europe
	9-dB noise figure
Antenna	Transmit: 6-element colinear slot array, 9-dB gain, $11^{\circ} \times 360^{\circ}$ beam tilted 7° above equatorial plane (maximum gain at about 45°N latitude)
	Receive: 3-element cloverleaf array, 4-dB gain, $40^{\circ} \times 360^{\circ}$ beam
Design Life	1.5 yr
Orbit	Synchronous equatorial
Orbital History	Launched 6 Apr 1965
	Commercial service use from 28 Jun 1965 to Jan 1969, and from 29 Jun to 13 Aug 1969 (to fill coverage gap caused by Intelsat IIIB outage)
	Delta launch vehicle
Developed for	Comsat Corporation/Intelsat
Developed by	Hughes Aircraft Company
Operated by	Comsat Corporation for Intelsat

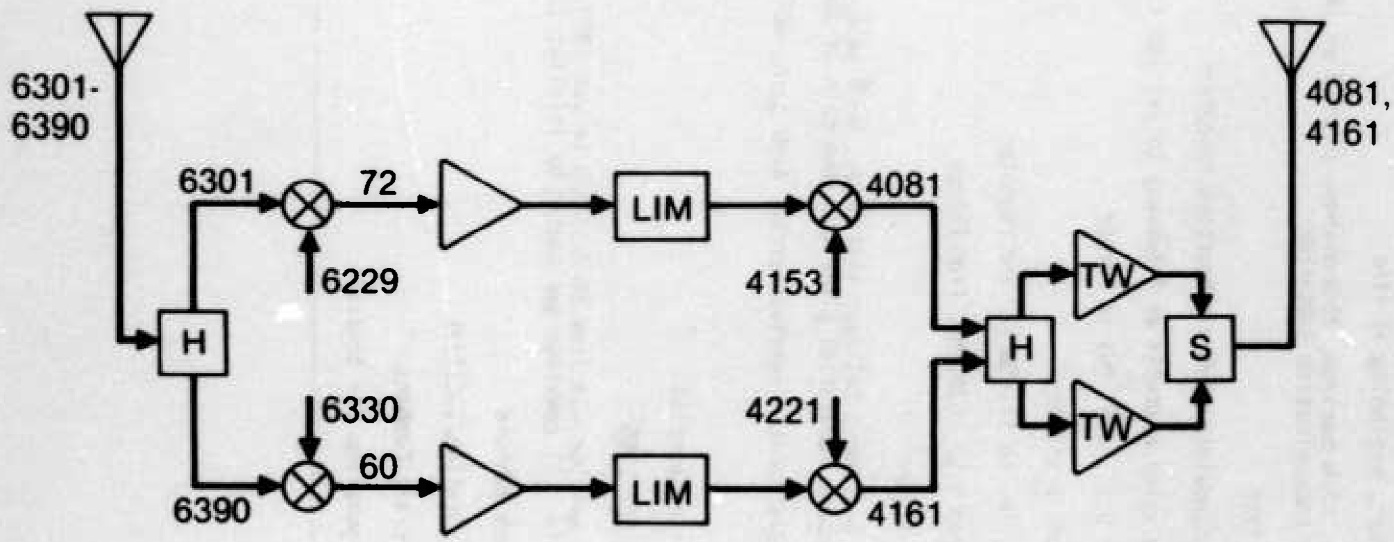


Figure 4-2. Early Bird Communication Subsystem

4.2 INTELSAT II (Refs. 117, 125-128)

Intelsat II was developed as a follow-on to Early Bird (Intelsat I). A prime factor in the timing of the Intelsat II program was the NASA need for multichannel communications with overseas ground and shipborne tracking stations to aid the Apollo program. Formerly, these communication links depended on high frequency radio, but the increase in manned space flights required improved quality and reliability. The Intelsat II satellites were designed to satisfy NASA requirements and to have additional capacity for other commercial traffic.

The design of the Intelsat II satellite was derived from the Syncom 3 and Early Bird designs. Mechanically, all three satellites were similar (Intelsat II is shown in Figure 4-3). The communication subsystem of Intelsat II (Figure 4-4) had a single, wide bandwidth repeater rather than the pair of narrowband repeaters used on Early Bird. The antenna pattern was centered at the equator to provide equal coverage to both northern and southern hemispheres. Parallel TWTs were used in the transmitter to compensate for this wider beamwidth (the Early Bird antenna pattern covered only the northern hemisphere). Therefore, the communication capacity of Intelsat II was the same as that of Early Bird. Table 4-2 gives details of the Intelsat II satellite.

The first Intelsat II satellite (IIA) was launched in October 1966 but, because of an apogee motor malfunction, its final orbit was elliptical with a synchronous altitude apogee. It was used for communications in the Pacific area a few hours a day until satellite IIB was launched. After that, it was used occasionally for ground station tests. Satellites IIB, IIC, and IID were all launched successfully and operated properly. They were used both in regular commercial service and in the NASA communications network. These three satellites, along with Early Bird, were "retired" by 1971 when the Intelsat III satellites became operational.

Figure 4-3. Intelsat II Satellite

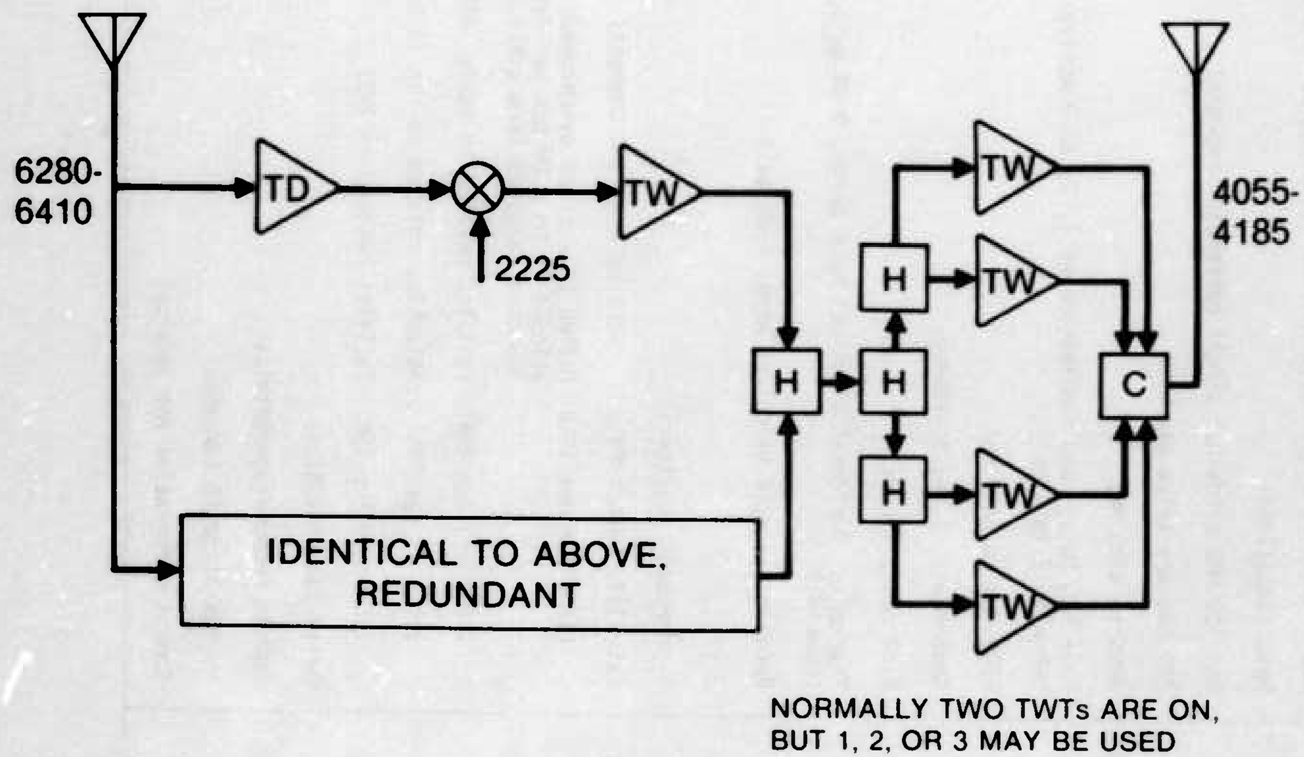


Figure 4-4. Intelsat II Communication Subsystem

Table 4-2. Intelsat II Details

Satellite	Cylinder, 56-in. diameter, 26.5 in. high, overall height 45 in.
	192 lb in orbit, beginning of life
	Solar cells and NiCd batteries, 85 W initially, 75 W minimum after 5 yr
	Spin-stabilized
Configuration	One 130-MHz bandwidth single conversion repeater
Capacity	240 two-way voice circuits
Transmitter	4055 to 4185 MHz
	Four 6-W TWTs: any combination of 1, 2, or 3 active 12-W output, 15.4-dBW ERP with 2 TWTs on
Receiver	6280 MHz to 6410 MHz
	Redundant: 1 on, 1 standby
	6-dB noise figure
Antenna	Transmit: 4-element biconical horn array, 5-dB gain, $12^{\circ} \times 360^{\circ}$ beamwidth
	Receive: Single biconical horn, 4-dB gain
Design Life	3 yr
Orbit	Synchronous equatorial
Orbital History	Satellite / Launch Date / Service Area and Comments
	IIA / 26 Oct 1966 / Failed to achieve synchronous orbit; 12-hr orbit allowed 4- to 8-hr use per day until IIB was launched; decayed from orbit on 7 Sept 1982
	IIB / 11 Jan 1967 / Pacific; retired in early 1969
	IIC / 7 Apr 1967 / Atlantic; retired in Feb 1970
	IID / 27 Sep 1967 / Pacific; retired in 1971
	Delta launch vehicle
Developed for	Comsat Corporation/Intelsat
Developed by	Hughes Aircraft Company
Operated by	Comsat Corporation for Intelsat

4.3 INTELSAT III (Refs 117, 128-132)

Work on the Intelsat III satellites began in 1966 about the time the first Intelsat II was launched. The goal of the Intelsat III program was to develop satellites with greater capacity than the previous satellites, which had a multiple access capability allowing communications between any pair of terminals within view of the satellite. The Intelsat III program was the first to provide global service, with satellites serving each of the three ocean areas of the world. This fulfilled a goal defined in the original charter of the Intelsat organization.

The Intelsat III satellites (Figure 4-5) were larger than the Intelsat II satellites. The basic design was similar, with equipment mounted on a platform within a spinning, cylindrical body on which solar cells were mounted. A despun antenna was the major new feature of the Intelsat III design. The beamwidth of the antenna was optimized for earth coverage and provided significantly more gain than the antennas on earlier satellites. Increased gain was the major reason the Intelsat III communication capacity was five times that of Intelsat II. Details of the satellite are given in Table 4-3. The communication subsystem (Figure 4-6) had two independent repeaters, each with a bandwidth of 225 MHz.

Originally, the Intelsat III program was to include six launches. During the course of the program, however, partially because of the failure of the first launch, the program was extended to eight launches. The seventh satellite was fabricated from available spare parts, and the eighth was the refurbished prototype. Between December 1968 and July 1970, five of the eight satellites were successfully placed into synchronous orbit, and all five operated satisfactorily. A component failure reduced the capacity of Intelsat IIIC, but it was moved from the Pacific to the Indian Ocean area, where it provided acceptable service in view of the lower traffic density. Beginning in 1972 the Intelsat III satellites were removed from service as the Intelsat IV satellites became available.

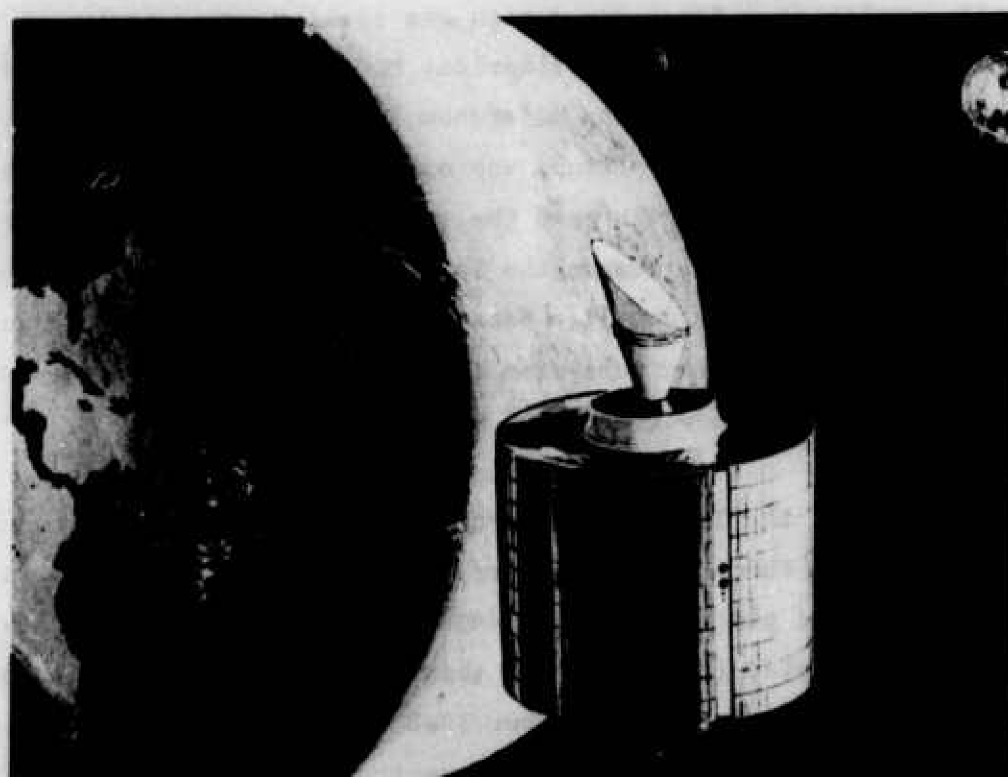
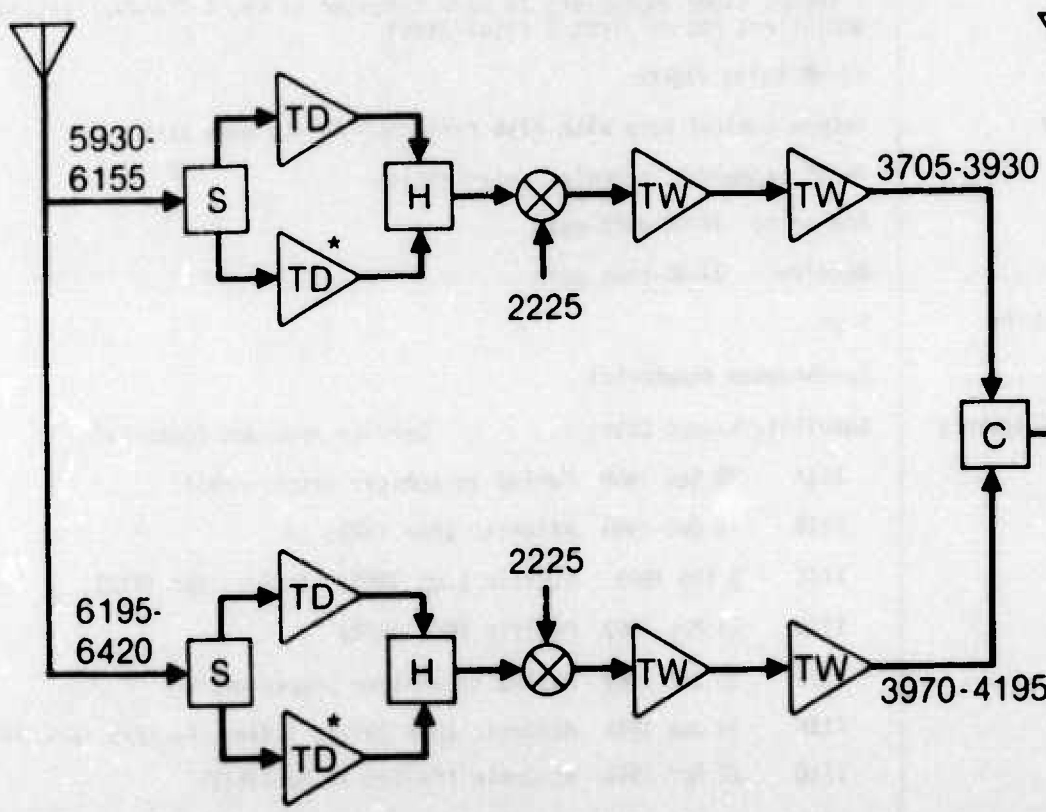


Figure 4-5. Irtelsat III Satellite

Table 4-3. Intelsat III Details

Satellite	Cylinder, 56-in. diameter, 41 in. high, overall height 78 in. ~330 lb in orbit, beginning of life Solar cells and NiCd batteries, 160 W at beginning of life, 130 W minimum after 5 yr Spin-stabilized, 90 rpm
Configuration	Two 225-MHz bandwidth single conversion repeaters
Capacity	1200 two-way voice circuits or 4 TV circuits
Transmitter	3705 to 3930 and 3970 to 4195 MHz Each repeater has a low level TWT driving a high level TWT 10-W output, 27-dBW ERP each repeater (22-dBW minimum at edge of earth)
Receiver	5930 to 6155 and 6195 to 6420 MHz 2 tunnel diode amplifiers in each repeater (1 on, 1 standby) (standby amplifiers not on first 3 satellites) <7-dB noise figure
Antenna	Despun conical horn with flat reflector 45° to horn axis 19.3° beamwidth, circular polarization Transmit: 18-dB peak gain Receive: 21-dB peak gain
Design Life	5 yr
Orbit	Synchronous equatorial
Orbital History	Satellite / Launch Date / Service Area and Comments[a] IIIA / 18 Sep 1968 / Failed to achieve proper orbit IIIB / 18 Dec 1968 / Atlantic (Mar 1970) IIIC / 5 Feb 1969 / Pacific (Jun 1969), Indian (Apr 1979) IIID / 21 May 1969 / Pacific (Nov 1972) IIIE / 25 Jul 1969 / Failed to achieve proper orbit IIIF / 14 Jan 1970 / Atlantic (Mar 1972), Indian, Pacific (Dec 1974) IIIG / 22 Apr 1970 / Atlantic (failed in Mar 1972) IIIH / 23 Jul 1970 / Failed to achieve proper orbit Delta launch vehicle
Developed for	Comsat Corporation/Intelsat
Developed by	TRW Systems Group (6% subcontracted in Western Europe and Japan)
Operated by	Comsat Corporation for Intelsat

[a]Dates indicate end of active service. The Intelsat III satellites are no longer available for service.



*Spare TD and switching not in first 3 satellites

Figure 4-6. Intelsat III Communication Subsystem

4.4 INTELSAT IV (Refs 133-139)

The Intelsat III satellites were a significant improvement over the previous Intelsat satellites. However, prior to the first Intelsat III launch, it was recognized that the continually increasing demand for communication satellite services would shortly require even larger satellites in orbit. Therefore, design work was begun on Intelsat IV about the time the first Intelsat III satellites were brought into service. The main requirements for the Intelsat IV satellites were to provide increased capacity and operational flexibility while remaining compatible with existing ground terminals.

The design of Intelsat IV (Figure 4-7) differs significantly from that of Intelsat III and was based on the Tactical Communications Satellite (Tacsat) design. The antennas and communications electronics are all mounted on a platform that is despun relative to the main body of the satellite in order to remain pointed at the earth. All other equipment is mounted within the large cylindrical satellite body, which spins to provide stabilization. Like Tacsat, but unlike other previous satellites, the spin axis was not the axis of the maximum moment of inertia, and special attitude control devices were required to maintain stability. The Intelsat IV solar array was much larger than that of Intelsat III, thereby allowing a significant increase in total transmitter power. Additional details are given in Table 4-4.

Previous Intelsat satellites all had one or two communication channels, and with each new design, increased capacity was achieved by increasing the channel bandwidth. The resulting capacity was always limited by the available transmitter power. Since the Intelsat III design used 450 MHz of the 500-MHz allocation, the Intelsat IV design was bandwidth-limited, and 12 separate repeaters were used to achieve more efficient spectrum utilization. The total repeater bandwidth is 432 MHz, but the total capacity using earth coverage antennas is 3000 telephone circuits - 2.5 times the capacity of Intelsat III. A block diagram of the Intelsat IV communication subsystem is shown in Figure 4-8.

Intelsat IV was the first satellite to have narrowbeam antennas. It has two transmitting antennas with 4.5 deg beamwidths in addition to the earth coverage ($\sim$ 17 deg beamwidth) receiving and transmitting antennas. Up to four repeaters may be connected to each narrowbeam antenna, providing a maximum satellite capacity of 9000 telephone circuits. Under normal operating conditions, each Intelsat IV provides a capacity of 4000 to 6000 circuits. The maximum capacity is not realized because of the inefficiencies incurred when several transmissions share a repeater.

All eight Intelsat IV satellites have been launched, with only one unsuccessful launch. The first launch was in January 1971 and the last in May 1975. Some continued in active service until 1981. All are now spare satellites, with the newer Intelsat IV-As and Vs assuming all active roles.

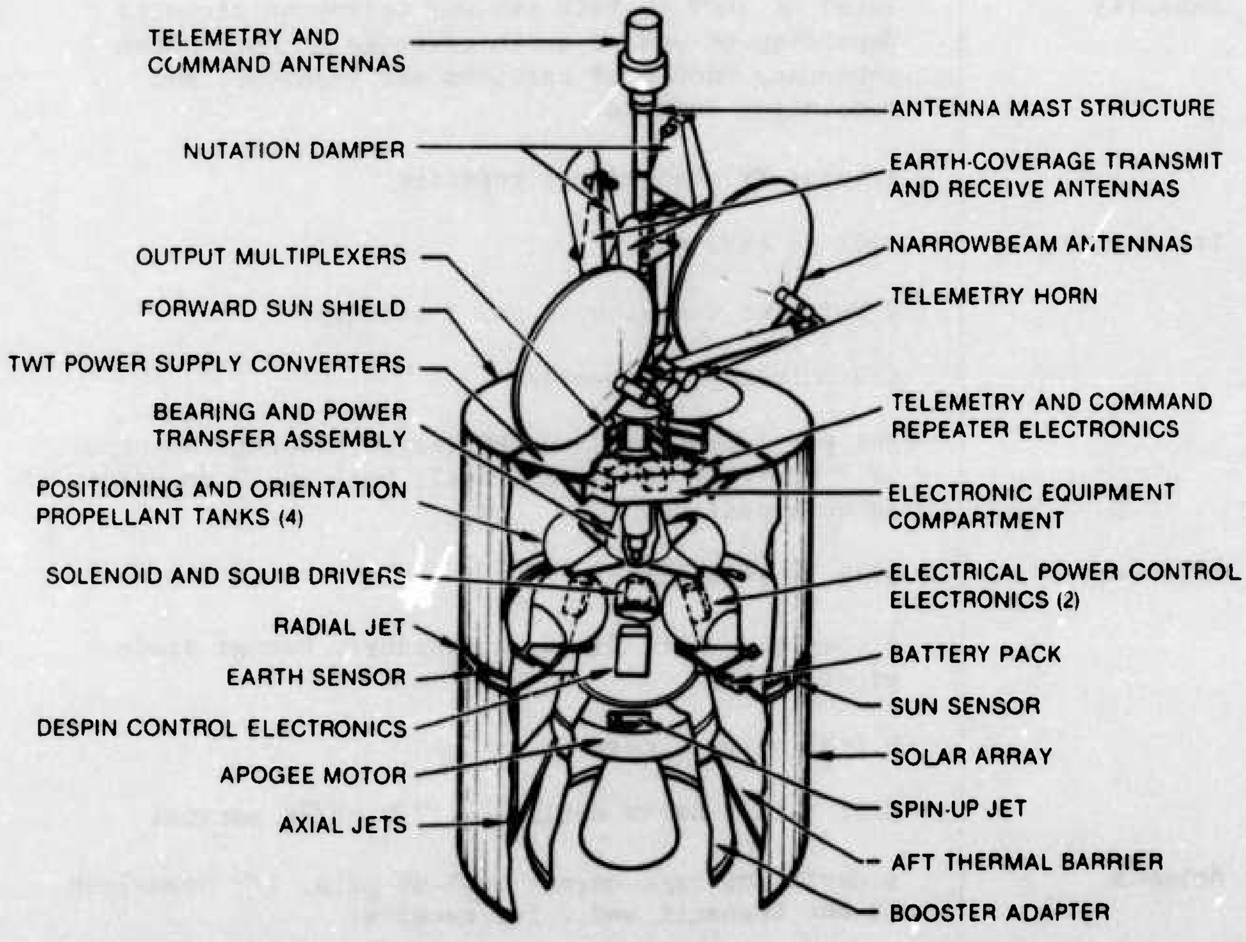


Figure 4-7. Intelsat IV Satellite

Table 4-4. Intelsat IV Details

Satellite	Cylinder, 94-in. diameter, 111 in. high, overall length 210 in. (17.5 ft)
	~1600 lb in orbit, beginning of life
	Solar cells and NiCd batteries, 570 W initially, 460 W at end of life
	Spin-stabilized, gyrostat, 50 to 60 rpm, antenna pointing error $<\pm 0.35^{\circ}$ (each axis)
Configuration	Twelve 36-MHz bandwidth single conversion repeaters
Capacity	Total of 3000 to 9000 two-way telephone circuits depending on use of earth coverage or narrowbeam antennas, number of carriers per repeater, and modulation formats
	1 color TV channel per repeater
Transmitter	3707 to 4193 MHz
	2 TWTs per repeater (1 on, 1 standby)
	6-W output per repeater
	ERP per repeater: 22.0 dBW (earth coverage antenna), 33.7 dBW (narrowbeam antenna), both at -3 dB points of antenna pattern
Receiver	5932 to 6418 MHz
	4 complete units (1 on, 3 standby), tunnel diode preamplifiers
	8.2-dB noise figure
	G/T: -18.7 dB/$^{\circ}$K minimum, -17.2 dB/$^{\circ}$K nominal
Antenna	4 earth coverage horns, 20.5-dB gain, 17° beamwidth (2 for transmit and 2 for receive)
	2 narrowbeam parabolas, 50-in. diameter, 31.7-dB gain, 4.5° beamwidth, steerable in the 17° earth coverage cone

Table 4-4. Intelsat IV Details (Continued)

	All 6 antennas mounted on a despun platform and circularly polarized		
Design Life	7 yr		
Orbit	Synchronous equatorial, stationkeeping to $\pm 0.1^{\circ}$N-S and E-W		
Orbital History	Satellite	Launch Date	Service Area and Comments
	F-2	25 Jan 1971	Atlantic, no longer available for service
	F-3	19 Dec 1971	Atlantic, spare, 40°W longitude
	F-4	23 Jan 1972	Pacific, no longer available for service
	F-5	13 Jun 1972	Indian, then Pacific, no longer available for service
	F-7	23 Aug 1973	Atlantic and Indian, spare 40°W longitude
	F-8	21 Nov 1974	Pacific, then Atlantic, spare 1°W longitude
	F-6	20 Feb 1975	Launch vehicle failure
	F-1	22 May 1975	Indian, then Atlantic, spare, 53°W longitude
	Atlas-Centaur launch vehicle		
Developed for	Comsat Corporation/Intelsat		
Developed by	Hughes Aircraft Company, ~20% subcontracted to companies in Western Europe, Japan, and Canada		
Operated by	Intelsat		

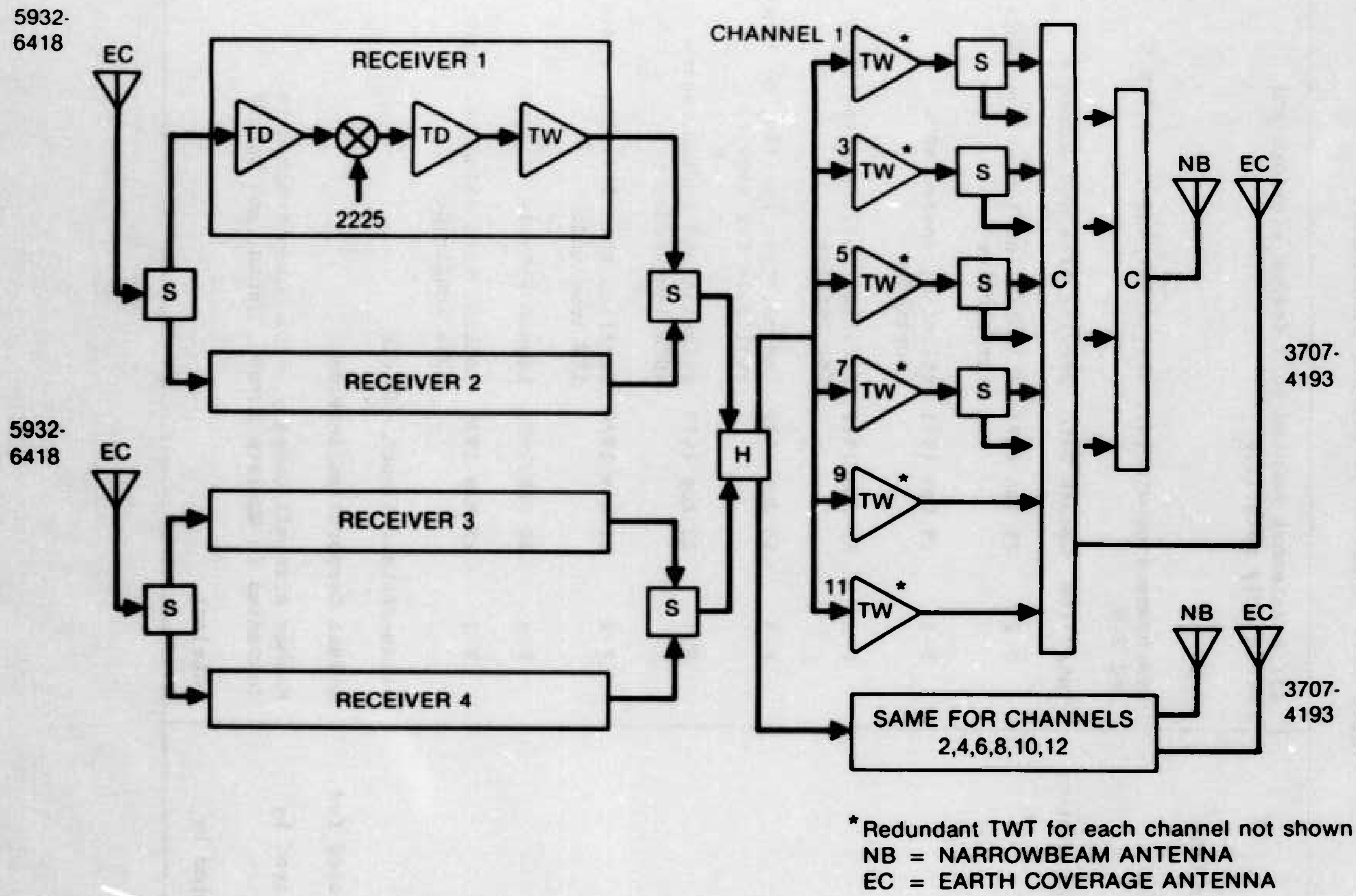


Figure 4-8. Intelsat IV Communication Subsystem

4.5 INTELSAT IV-A (Refs. 140-149)

The North Atlantic area has always had the largest volume of communications traffic, and is the area that paces the introduction of higher capacity satellites into the Intelsat system. By 1972, two Intelsat IV satellites operating together were required in this area. According to the projections of capacity demand, these two satellites would have been saturated by the end of 1975. Providing more capacity would require either a third Intelsat IV or a new satellite of larger capacity. Since the first alternative would force several ground stations to construct another antenna, Intelsat chose to develop Intelsat IV-A.

The support subsystems and satellite body of Intelsat IV-A are the same as that for Intelsat IV except for more efficient solar cells. Figure 4-9 shows the Intelsat IV-A satellite. It has five communication antennas: global coverage receive, global coverage transmit, spot beam receive, and two spot beam transmit. The new antennas and communication electronics allow an increase to twenty 36-MHz channels from the twelve on Intelsat IV (see Figure 4-10). Four channels are devoted to global coverage. All four channels pass through one of the redundant global coverage receivers. Each channel has redundant 6-W TWTs. Sixteen channels are connected to the spot beam antennas and are divided into A and B groups, each with eight channels. All the channels within a group use separate frequencies, but the corresponding channels of the two groups (e.g., 1A and 1B) use the same frequencies. There are four receivers for these channels, but only two are used at a time (one for each group). The spot beam channels use 5-W TWTs, with one spare TWT available for every two channels. Additional details are given in Table 4-5.

The spot beam antennas have east and west beams* to prevent interference between overlapping channels; the A channel of each pair uses one

*The satellites are positioned over oceans, with the spot beams serving the continental areas on either side of the ocean. Any terminals near the satellite longitude are between the two beams and must use the global coverage channels.

beam, and the B channel uses the other beam. There is at least 27-dB isolation between the two beams. The receive antenna has two sets of feed horns that produce the two beams (east and west). One transmit antenna has four sets of feed horns that produce northeast, northwest, southwest, and southeast beams. The eastern pair of beams is isolated from the western pair, but the north and south members of a pair are not isolated since they carry no overlapping channels. Six channels are connected to the west beams of this antenna and six to the east beams. Each of the channels connected to the east side may have its power split in any proportion between the northeast and southeast beams and similarly for channels connected to the west side. The other transmit antenna has two sets of feed horns that produce northeast and northwest beams, and two channels are connected to each of these beams. In an optional mode, two of these channels may be switched to a global coverage antenna, in which case the other two must be turned off. A considerable number of switches in the communication subsystem allow great flexibility in routing signals, subject only to the constraint that the A and B channels of any one pair are not simultaneously on the same beam.

Each beam on both the receive and transmit antennas is formed by a set of feed horns that shape the beams for coverage of the proper land masses. The coverage being used is adequate for Atlantic, Pacific, and Indian Ocean areas with fixed feed horns and fixed reflectors, with only one exception. This fact simplifies the satellites since no antenna gimbaling is required, and it also allows the flexibility to move a satellite from one ocean area to another. The exception to the general coverage is an additional feed horn that must be switched into the west receive beam and southwest transmit beam to provide adequate coverage of New Zealand from an Intelsat IV-A in the Pacific region.

Initially three Intelsat IV-A satellites were ordered, followed by a second order for three more, in 1974. All six were launched between September 1975 and March 1978. The first three were placed into service in the Atlantic

region, and are still there even though Intelsat Vs began operating in 1981. The fourth was lost as the result of a launch vehicle failure. The last two were in the Indian Ocean region for several years, then moved to the Pacific region when replaced by two Intelsat V satellites.

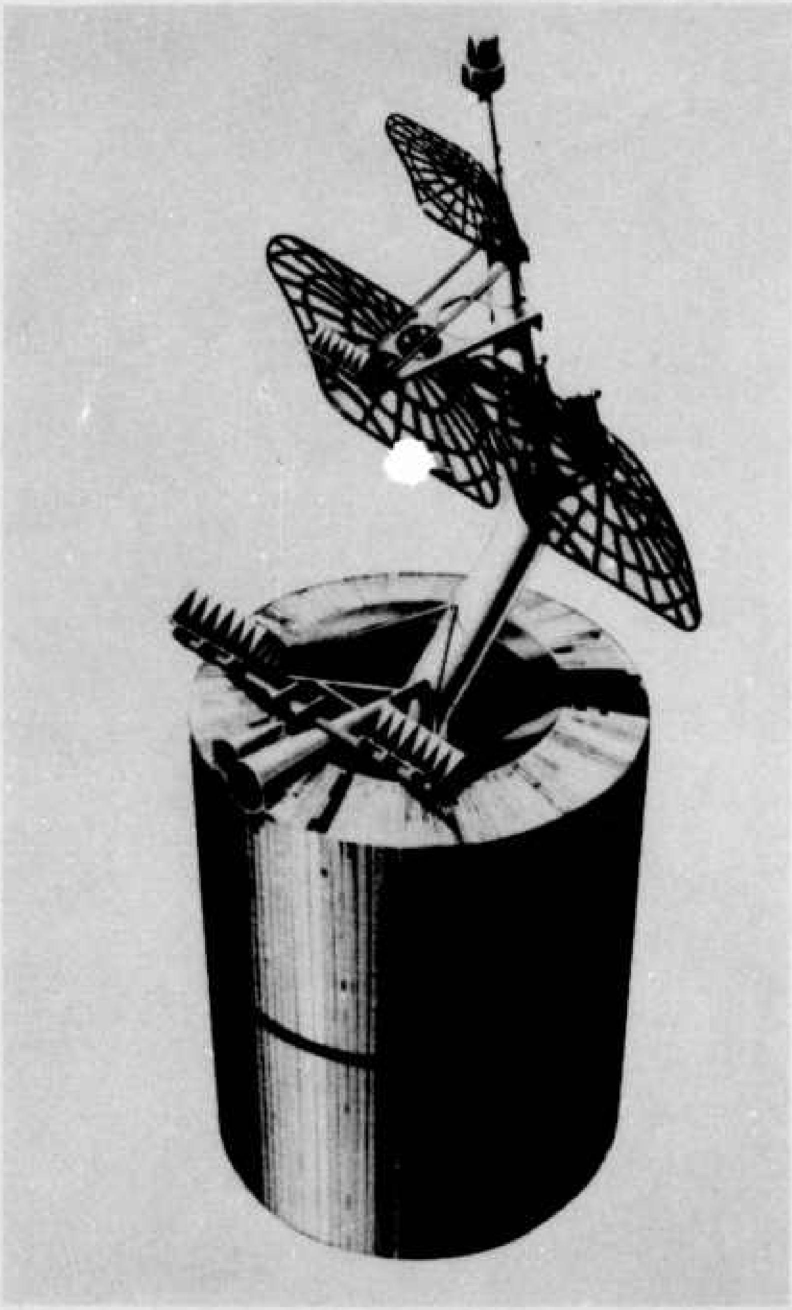


Figure 4-9. Intelsat IV-A Satellite

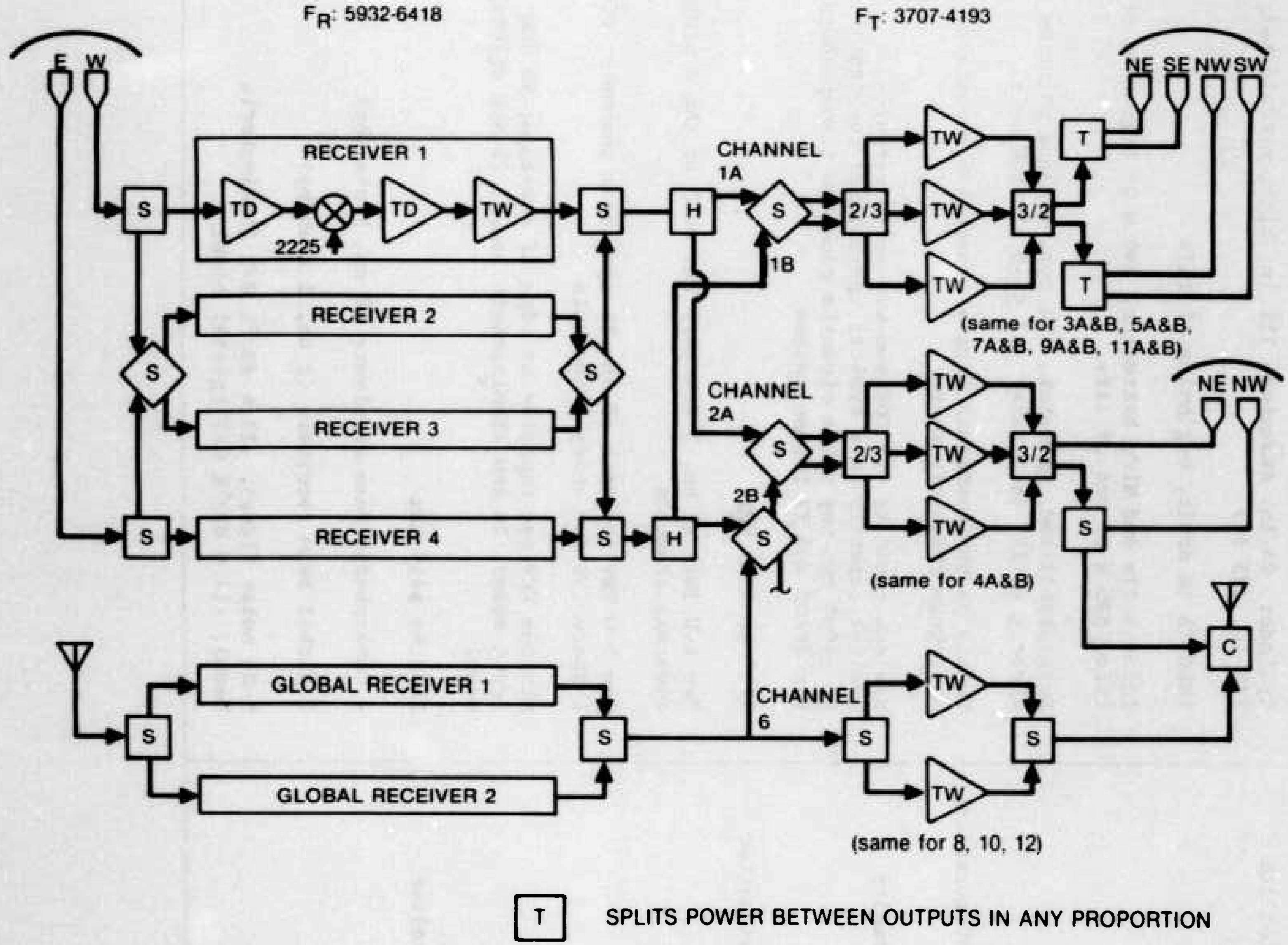


Figure 4-10. Intelsat IV-A Communication Subsystem

Table 4-5. Intelsat IV-A Details

Satellite	Cylinder, 94-in. diameter, 111 in. high, overall height 275 in. (23 ft)
	1820 lb in orbit, beginning of life
	Solar cells and NiCd batteries, 590 W at beginning of life, 525 W at end of life
	Spin-stabilized, gyrostat, ~50 rpm, antenna pointing error $\leq \pm 0.25^{\circ}$ (N-S axis) and $\leq \pm 0.2^{\circ}$ (E-W axis)
Configuration	Twenty 36-MHz bandwidth single conversion repeaters, dual beam frequency reuse
Capacity	Maximum capacity ~15,000 two-way voice circuits; nominal capacity in a typical operational configuration is ~6000 two-way voice circuits plus two transponders for SPADE and TV transmissions
Transmitter	3707 to 4193 MHz
	Two 6-W TWTs (1 on, 1 standby) for each of the 4 global coverage channels
	One 5-W TWT for each of the 16 spot beam channels, with 1 spare TWT for every 2 channels
	Minimum ERP per repeater at edge of coverage; 29 dBW (spot beam), 26 dBW (hemispheric beam), 22 dBW (global beam)
Receiver	5932 to 6418 MHz
	4 hemispheric beam receivers (2 on, 2 standby)
	2 global beam receivers (1 on, 1 standby)
	8-dB noise figure, -11.6 dB/$^{\circ}$K G/T (hemispheric beam), -17.6 dB/$^{\circ}$K G/T (global beam)

Table 4-5. Intelsat IV-A Details (Continued)

Antenna	2 earth coverage horns (1 transmit, 1 receive) 3 spot beam antennas with multiple feeds to generate coverage patterns approximating continental shapes (2 transmit, 1 receive); at least 27-dB isolation between eastern and western lobes of each antenna; each antenna is approximately square except for rounded corners, 54 in. across for transmit, 35 in. for receive All antennas mounted on a despun platform and circularly polarized		
Design Life	7 yr		
Orbit	Synchronous equatorial, stationkeeping to $\pm 0.1^{\circ}$N-S and E-W		
Orbital History	Satellite	Launch Date	Service Area and Comments
	F-1	25 Sep 1975	Atlantic, 31°W longitude[c]
	F-2	29 Jan 1976	Atlantic, then Indian, 57°E longitude[b,c]
	F-4	26 May 1977	Atlantic, 21.5°W longitude[c]
	F-5	29 Sep 1977	Launch vehicle failure
	F-3	6 Jan 1978	Indian, then Pacific, 179°E longitude[b,c]
	F-6	31 Mar 1978	Indian, then Pacific, 174°E longitude[a]
	Atlas-Centaur launch vehicle		
Developed for	Comsat Corporation/Intelsat		
Developed by	Hughes Aircraft Company and subcontractors in Western Europe, Japan, and Canada		
Operated by	Intelsat		

[a]Intelsat system active satellite.
[b]Intelsat system spare satellite.
[c]Provides leased domestic service.

4.6 INMARSAT SYSTEM (Refs. 150-163)

In 1972 the Intergovernmental Maritime Consultative Organization (IMCO) began serious studies of an international maritime satellite system for which it had issued a statement of requirements in 1970. These studies covered institutional, operational, technical, and economic aspects of the system. The primary purpose of the system is to provide high quality, rapid, reliable communications between commercial ships and the international public communication networks (i.e., telephone, telex). Provisions for handling distress messages will be included. In addition, the system might also provide a position determination service.

IMCO has about 80 member nations, of which about 20 were active in the initial studies. In April 1975, IMCO convened an international conference to begin establishing the system; 48 nations were represented. It was unanimously agreed that such a system is necessary and that a new organization - the International Maritime Satellite Organization (Inmarsat) - should be formed to operate the system. Details of organizational and financial matters were assigned to several working groups in preparation for a second conference in February 1976. A third conference was held in September 1976, after which the Inmarsat Convention and Operating Agreement were opened for ratification by interested governments. The conference also established an international preparatory committee to work on technical, economic, marketing, and organizational matters until the ratification process was completed.

The Inmarsat Convention entered into force in July 1979. The initial membership of Inmarsat included 26 nations; that number increased to 37 by May 1983. The investment share of each nation is related to both the tonnage of ships registered with it and the volume of communications to and from it. (For the U.S. these factors are far from equal since many ships registered in other countries are U.S. owned and will communicate mostly with the U.S.) Nations with large investment shares are the U.S. (23.4%), U.S.S.R. (14.1%), United Kingdom (9.9%), Norway (7.9%), and Japan (7.0%). Comsat Corporation is the U.S. representative in Inmarsat.

The Inmarsat system is composed of four segments. Satellites are either leased or owned by Inmarsat. Coast earth stations are owned and operated by Inmarsat members. Some of them provide tracking, telemetry, and command facilities for Inmarsat satellites. Ship earth stations are owned (or leased) and operated by shipowners. Network control is exercised from the Inmarsat Operations Control Centre in London.

For its initial space segment, Inmarsat chose to lease satellites already existing or in development, in order to begin operations as early as possible. Several configurations were studied. The one chosen is a combination of Marisat and Marecs satellites and a maritime communication subsystem on the fifth and subsequent Intelsat V satellites. Satellite details are available in the appropriate sections of this report. On February 1, 1982, Inmarsat took over the use of the three Marisat satellites and began providing service. A short time later, the first Marecs satellite was added to the system and became the primary Atlantic region satellite. The first Intelsat V with the maritime subsystem was launched in September 1982 and became the primary Inmarsat satellite in the Indian Ocean in January 1983. In both cases the older Marisat is the spare, while the Pacific Marisat is the only Inmarsat satellite in that region. By the fall of 1984, there will be one Marecs and one Intelsat V in each of the Atlantic and Pacific regions and two Intelsat Vs in the Indian Ocean region. The Marisats will have been retired.

Inmarsat is currently preparing for a second generation of satellites. A contract will be awarded in the first half of 1984 and the first launch is planned for 1988. These satellites will include at least one channel for testing an aeronautical communications service.

When Inmarsat began operations, five coast stations and about 1000 ship stations were functioning. Except for two new earth stations, the others were previously in use with the Marisat satellites. By the end of 1983 there should be about 12 coast stations and over 2000 ship stations. Typical coast and ship station characteristics are listed in Table 4-6.

Table 4-6. Inmarsat Station Characteristics

Parameter	Coast Earth Stations	Ship Earth Stations			
		A	B[a]	C[a]	D[a]
Transmit Frequencies, MHz	6410 - 6425[b]	1636.5 - 1645	same	same	same
Receive Frequencies, MHz	4180 - 4200[b]	1535 - 1543.5	same	same	same
Transmit ERP, dBW	≤70	36	~26	~19	≥40
Receive G/T, dB/°K	≥32	-4	~-12	~-19	~5
Typical Antenna diameter, ft	31-40	3	~1-1/2	<1	~10
Ship station capacity	---	1 voice channel or 2400 bps data	1 voice channel (reduced quality) or 2400 bps data	Telegraphy or 2400 bps data	Multichannel voice or 56 kbps data

[a]Tentative data

[b]Broader than currently used. Coast stations also have L-band (1650/1550 MHz) transmission and reception for network control and test signals.

4.7 INTELSAT V (Refs. 169-182)

Forecasts of Intelsat traffic project steady increases into the 1980s and, consequently, new model satellites must be introduced into the system at intervals of about four to five years. The Intelsat IV-A satellites were first used in 1975. These satellites provide a moderate capacity increase without requiring significant ground terminal changes. However, further capacity increases are not practical with a simple stretching of the Intelsat IV/IV-A design, so development of a new satellite was begun in 1976. The new satellite (Intelsat V) is now in use in both the Atlantic and Indian Ocean regions. The Intelsat IV-A satellites provide supplementary service in the Atlantic region. They are currently the active satellites in the Pacific region, which has the lowest traffic volume of the three regions.

The Intelsat V satellites have two new design features that require significant ground terminal changes. The first feature is the use of dual polarization uplinks and downlinks in the 4- and 6-GHz bands. All previous Intelsat satellites used one polarization for uplinks and the orthogonal polarization for downlinks. This change requires improvements at all ground terminals to ensure isolation between the two polarizations. The dual polarizations are combined with the two independent beams (east and west) introduced on Intelsat IV-A. Together, these techniques triple the satellite capacity in the 4- and 6-GHz bands, compared with the Intelsat IV design. The second new feature is the use of the 11- and 14-GHz bands, and two independent beams are used with these bands also. The nations with the largest traffic volumes will use these new frequencies and must construct new terminals for them.

The Intelsat V satellites (Figure 4-11) have a rectangular body about six ft across. The sun tracking solar arrays, composed of three panels each, are deployed in orbit. On the earth-viewing face of the body is an antenna tower on which are mounted both the communications and telemetry, tracking, and command (TT&C) antennas and the feed networks for the large reflectors. The tower is fixed relative to the satellite body, but the three largest

reflectors deploy in orbit. The tower is about 15 ft tall and is constructed almost entirely with graphite fiber/epoxy materials for strength, lightweight, and thermal stability. The entire satellite weighs about 2200 lb in orbit and spans about 51 ft across the solar arrays.

The communication subsystem operates at the 4- and 6-GHz frequencies used by all previous Intelsat satellites as well as at 11 and 14 GHz. The 4- and 6-GHz bands have 21 transponders, 16 with 72- or 77-MHz bandwidths and five with 36- or 41-MHz bandwidths. The 16 wider transponders are operated with fourfold frequency reuse; there are four separate frequencies, each with four transponders. Within each co-frequency set, two transponders are assigned to west beams and two to east beams. Thus, these transponder pairs are kept independent by the angular separation of the beams - the same technique used on Intelsat IV-A. The pairs that share a common frequency and direction are kept independent by the assignment of one to a hemispheric beam and one to a smaller zone beam. These beams are separated, not by direction, but by orthogonal polarizations. Of the five narrower transponders, two use the east and west beams for twofold frequency reuse and the other three are global beams. The pair of narrow reuse transponders and/or one pair of hemispheric beam reuse transponders can be switched to use one of each pair for additional global service with the other turned off. For all of the reuse transponders, several possible transmit and receive connections are possible. These connections are shown in Figure 4-12, the communication subsystem block diagram.

The 11- and 14-GHz bands have six transponders, two each of 72-, 77-, and 241-MHz bandwidth. They are used in twofold frequency reuse through east and west spot beams. These transponders may be operated only at 11 and 14 GHz or may be cross connected with the other frequencies. For example, one transponder may be switched to 14-GHz receive and 4-GHz transmit and another to 6-GHz receive and 11-GHz transmit. The 4- and 6-GHz signals pass through the satellite with a single frequency conversion, whereas all 11- and 14-GHz signals use a 4-GHz intermediate frequency so that all interconnections can be done at a common frequency.

The 4/6-GHz hemispheric and zone beams are formed by one transmit and one receive antenna. Each is composed of a parabolic reflector and an 88-horn feed. These beams are not steerable, but there are switches in the zone beam feed matrices because the pattern required for the satellite serving the Indian Ocean is different from that required for the Atlantic and Pacific regions. The Atlantic and Indian Ocean beam patterns are shown in Figure 4-13. The 11/14-GHz spot beams are formed by parabolic reflectors that are each steerable over a limited portion of the northern hemisphere.

Table 4-7 summarizes the Intelsat V characteristics. The initial contract was for seven satellites; later an eighth and then a ninth were added to the contract. (The satellites called Intelsat V F-10 to F-15 are the Intelsat V-A series.) The first launch was in December 1980; the last is scheduled for 1985. The last three launches will be on an Ariane; the others on an Atlas-Centaur.

In mid-1978, Intelsat began a detailed study of the addition of a maritime communication subsystem (MCS) to some of the Intelsat V satellites. This subsystem has been developed and will be used as part of the Inmarsat system space segment. It was added to satellite 5 launched in September 1982 and also satellites 6 through 9.

The maritime subsystem makes use of some of the global beam equipment of the basic communications payload. An L-band (1.5/1.6 GHz) antenna and some communications equipment have been added (see Figure 4-14). The maritime subsystem performance is described in Table 4-8. Several other modifications were added to the satellite beginning with the fifth flight model. These modifications were primarily to increase reliability and reduce weight, the latter partially compensating for the maritime subsystem addition. Because of power subsystem limitations, not all the maritime and 11-GHz capacity can be used simultaneously. This is acceptable to Intelsat because the 11-GHz transponders are not expected to be used on all of the satellites.

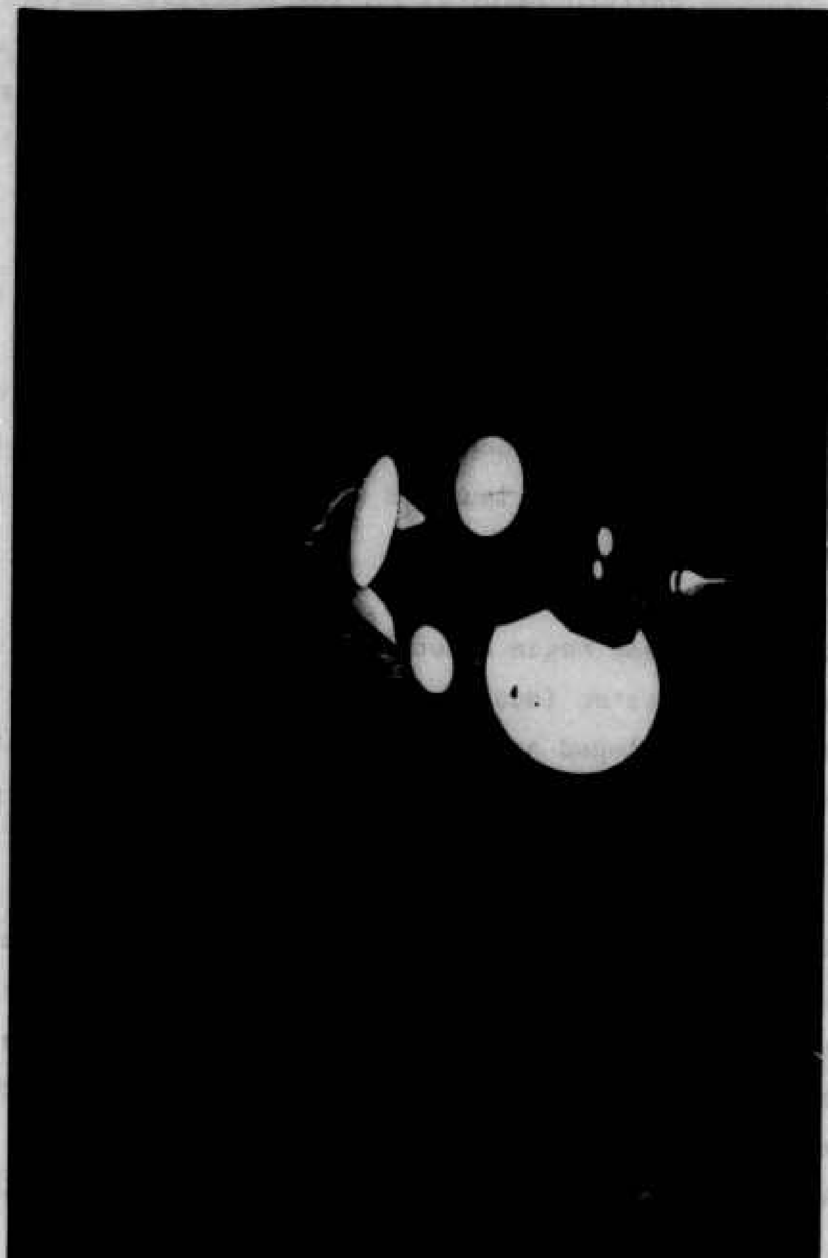
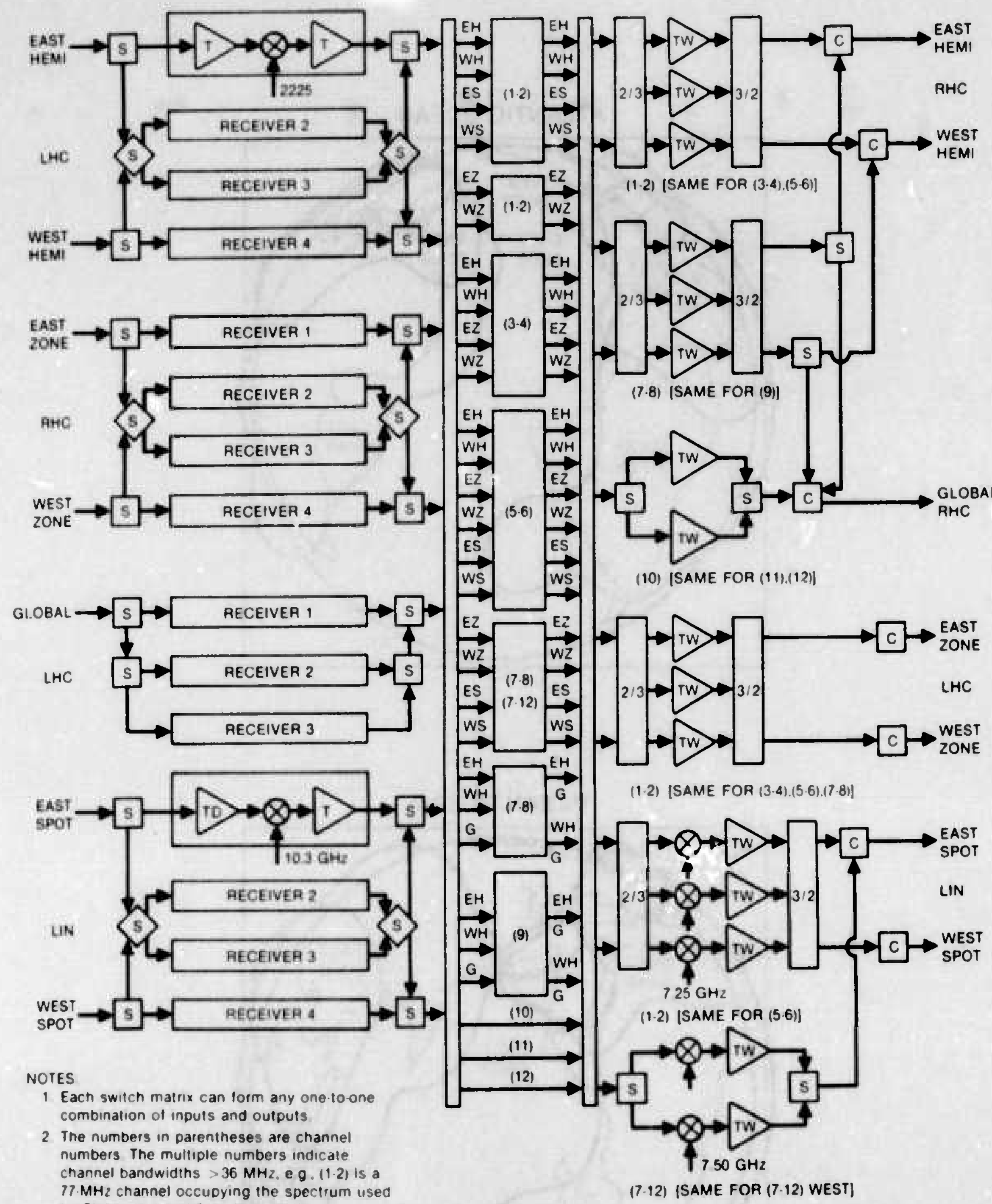


Figure 4-11. Intelsat V Satellite

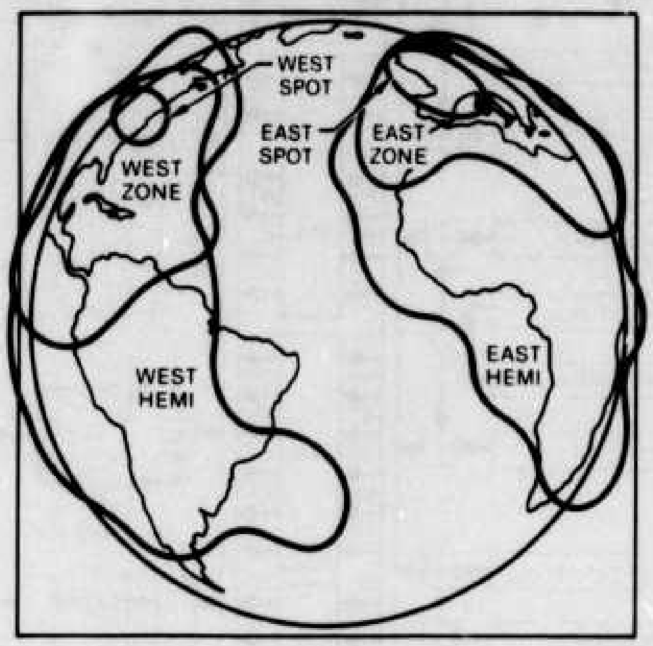


NOTES

1. Each switch matrix can form any one-to-one combination of inputs and outputs.
2. The numbers in parentheses are channel numbers. The multiple numbers indicate channel bandwidths >36 MHz, e.g., (1-2) is a 77-MHz channel occupying the spectrum used by Channels 1 and 2 on Intelsat IV.
3. LHC/RHC = Left/right-hand circular polarization,
   LIN = Linear polarization.
4. Channels (7-8) and (9) may each be used on both EH and WH, or on global.
5. Spot beam antennas have diplexers (not shown).
6. Combiners after transmitters also have inputs from unillustrated transmitters.

Figure 4-12. Intelsat V Communication Subsystem

ATLANTIC OCEAN



INDIAN OCEAN

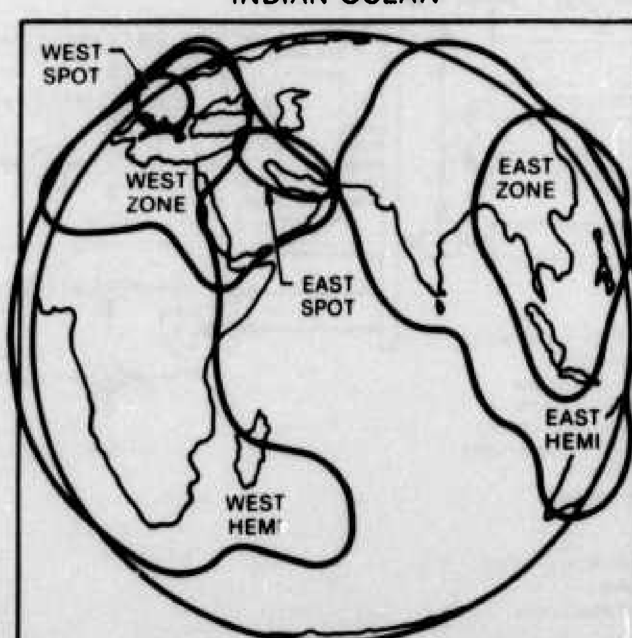


Figure 4-13. Intelsat V Antenna Patterns

Table 4-7. Intelsat V Details

Satellite	Rectangular body 5.4 x 5.8 x 6.6 ft, 51 ft across tips of deployed solar arrays, 21.7 ft height to top of antenna tower
	~2200 lb in orbit, beginning of life; ~1820 lb end of life (satellites with the maritime subsystem are about 80 lb more)
	Sun tracking solar arrays and NiCd (NiH_2 for F5 to F9) batteries, ~1800 W beginning of life, 1290 W minimum after 7 yr
	Three-axis stabilization, antenna pointing accuracy $\pm 0.2^{\circ}$ in pitch and roll, $\pm 0.5^{\circ}$ in yaw
Configuration	4/6 GHz: 21 single conversion repeaters with bandwidths of 36 to 77 MHz, dual beam and dual polarization frequency reuse
	11/14 GHz: 6 double conversion repeaters with bandwidths of 72 to 241 MHz, dual beam frequency reuse
Capacity	Nominal capacity in a typical operation configuration is 12,000 two-way voice circuits plus 2 television transmissions
Transmitter	4/6 GHz: 3704 to 4198 MHz
	Global beam: one 8.5-W TWT per repeater plus 1 spare per repeater
	Hemispheric beam: one 8.5-W TWT per repeater plus 1 spare per 2 repeaters
	Zone beam: one 4.5-W TWT per repeater plus 1 spare per 2 repeaters
	ERP (specified minimum): 23.5 dBW (global beam); 26 dBW (hemispheric or zone beam, 36-MHz repeaters); 29 dBW (hemispheric or zone beam, 72 to 77-MHz repeaters)
	11/14 GHz: 10.954 to 11.191, and 11.459 to 11.698 GHz
	One 10-W TWT per repeater (1 for 1 redundancy for 241-MHz repeaters, 1 for 2 redundancy for 72 to 77-MHz repeaters)
	ERP (specified minimums): 41.1 dBW (east spot), 44.4 dBW (west spot)
Receiver	4/6 GHz: 5929 to 6423 MHz
	5 active receivers with 6 spares
	G/T: -18.6 dB/°K (global beam), -11.6 dB/°K (hemispheric beam), -8.6 dB/°K (zone beam), all minimum values (all improve 2.6 dB for F5 to F9).
	11/14 GHz: 14.004 to 14.498 GHz
	2 active receivers with 2 spares
	G/T: 0.0 dB/°K (east spot), +3.3 dB/°K (west spot), both minimum values
Antenna	4/6 GHz: 2 earth coverage horns (1 transmit, 1 receive); $18^{\circ}/22^{\circ}$ beamwidths, 16.5 dB/14.5 dB minimum gains; 2 reflectors (96-in. diameter transmit, 61-in diameter receive) with 88-horn feeds, each generating 2 hemispheric beams (21.5 dB minimum gain) and 2 smaller zone beams (24.5 dB minimum gain); zone beams each overlap a portion of one of the hemispheric beams and are separated by orthogonal polarizations; beam shapes are optimized to cover specified terminal locations; circular polarization; minimum interbeam spatial or polarization isolation 27 dB

Table 4-7. Intelsat V Details (Continued)

	11/14 GHz: 2 reflectors (1 east, 1 west) each generating 1 beam for transmission and reception; west beam is 1.6° with minimum gain of 36 dB, east beam is 1.8° x 3.2° with minimum gain of 33 dB; each beam steerable over a limited portion of the earth; linear polarization; minimum interbeam spatial isolation 33 dB.		
Design Life	10 Yr		
Orbit	Synchronous equatorial, stationkeeping to ±0.1°N-S and E-W		
Orbital History	Satellite	Launch Date	Service Area and Comments
	F-2	11 Dec 1980	Atlantic, 34.5°W longitude[a,c]
	F-1	23 May 1981	Atlantic, then Indian, 60°E longitude[a,c]
	F-3	15 Dec 1981	Atlantic, 24.5°W longitude[a]
	F-4	5 Mar 1982	Atlantic, 27.5°W longitude[b,c]
	F-5	28 Sep 1982	Indian, 63°E longitude[a,c]
	F-6	19 May 1983	Atlantic, 18.5°W longitude[a]
	F-7	19 Oct 1983	Indian, 60°E longitude
	F-8	4 Mar 1984	Atlantic, 53°W longitude[a,c]
	F-9	Launch scheduled mid 1985	
	Atlas-Centaur launch vehicle (F-1 to F-6)		
	Ariane launch vehicle (F-7 to F-9)		
Developed for	Comsat Corporation/Intelsat		
Developed by	Ford Aerospace and Communications Corporation; approximately 23% subcontracted to companies in France, West Germany, U.K., Japan, and Canada		
Operated by	Intelsat		

[a]Intelsat system active satellite.
[b]Intelsat system spare satellite.
[c]Provides leased domestic service.

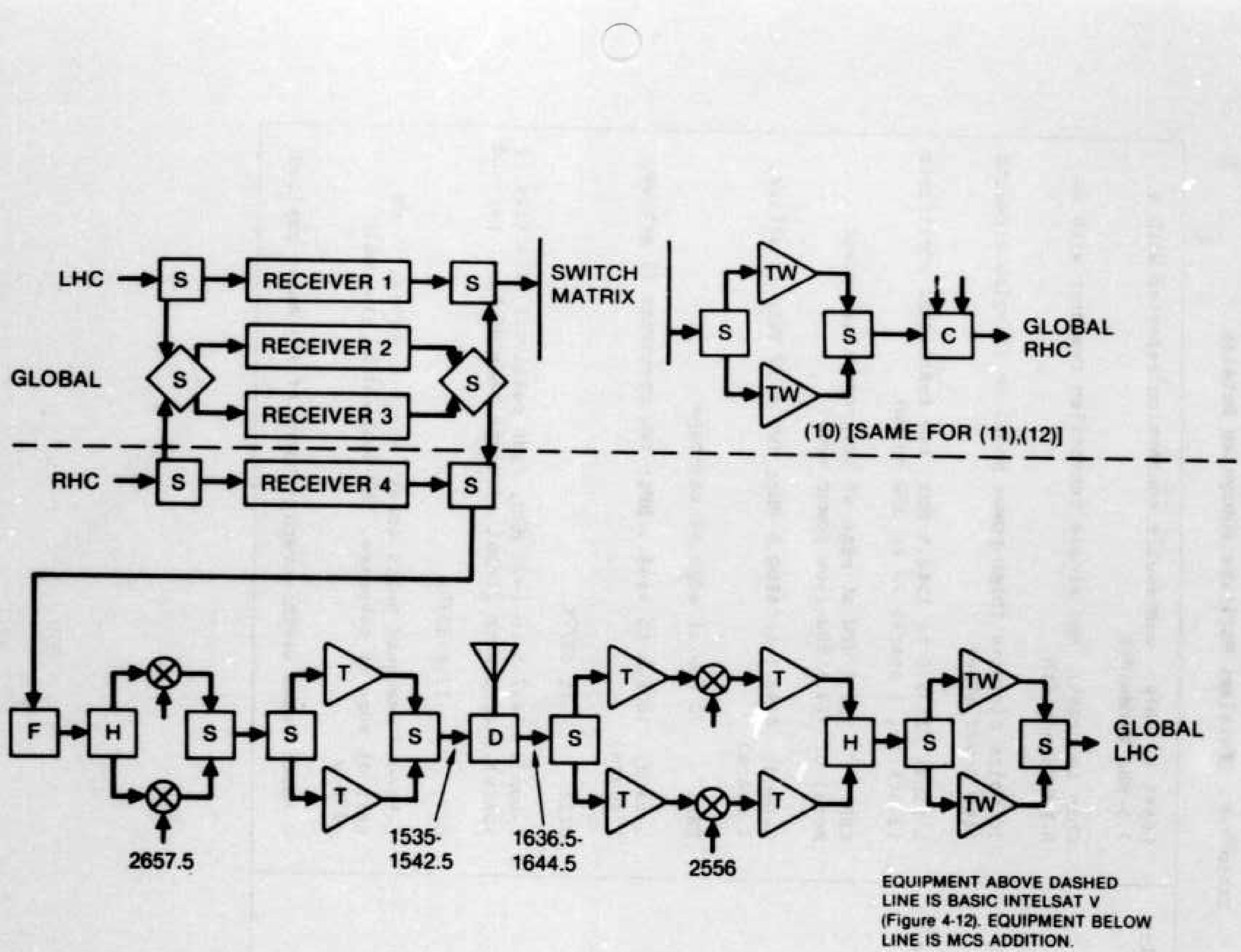


Figure 4-14. Intelsat V Maritime Communication Subsystem

Table 4-8. Intelsat Maritime Subsystem Details

Configuration	Coast to ship: one double conversion repeater with a 7.5-MHz bandwidth Ship to coast: one single conversion repeater with an 8-MHz bandwidth
Capacity	30 voice circuits (high power mode) or 15 voice circuits (low power mode)
Transmitter	L-Band: 1535.0 to 1542.5 MHz; two transistor amplifiers (1 active, 1 spare) 70 or 35W output ERP: $\geq$32.6 dBW at edge of coverage (high power mode) or $\geq$29.6 dBW (low power mode) C-band: 4192.5 to 4200.5 MHz; two 4.5W TWTs (1 active, 1 spare) ERP: 20 dBW at edge of coverage
Receiver	L-band: 1636.5 to 1644.5 MHz; two receivers (1 active, 1 spare) G/T: $\geq$-15 dB/^{o}K C-band: 6417.5 to 6425 MHz; four receivers (2 active, 2 spare) shared with global coverage beam of basic payload G/T: $\geq$-17.6 dB/^{o}K
Antenna	L-band: one quad helix array, earth coverage, 14 dB gain at edge of coverage, 18^{o} beamwidth, steerable $\pm$2^{o}E-W C-band: uses earth coverage horns of the basic payload

4.8 INTELSAT V-A (Refs. 182-184)

Intelsat V-A is a modification of the Intelsat V design. Development began late in 1979. As with previous changes to Intelsat satellites, the primary goal is to increase satellite capacity to keep ahead of traffic growth in the Atlantic region.

Externally, the satellite appears almost identical to the Intelsat Vs (Figure 4-11). Internally, there are numerous changes to improve performance, reliability, and communications capacity. Several weight saving measures were taken to compensate for the additional communications hardware. The internal arrangement of the communications hardware was modified for thermal balance. Satellite details (Table 4-9) are in many cases identical to those of Intelsat V.

In the communications subsystem (Figure 4-15) three global beam transponders were added. They use the same frequency as the existing, dedicated global beam transponders, but use the opposite polarization. Two channel 9 zone beam transponders were also added. They are separated from each other by the spatial discrimination between the east and west zone beams. They are separated from the existing channel 9 transponders by opposite polarizations. Another communications subsystem change is the addition of 4-GHz feed horns to the steerable east and west spot beam antennas, which were previously used only at 11 and 14 GHz. The channels received on the global beams can be switched between global transmit beams and these new 5-deg beams. These beams are intended for use with transponders leased by Intelsat for domestic communications systems. The last two satellites will have the capability to switch channels (1-2) and (5-6) between the 10.95- to 11.2-GHz band, available on all Intelsat V and V-As, and the 11.7- to 11.95-GHz band. This latter band will allow Intelsat more flexibility in use of international frequency allocations.

The first Intelsat V-A is expected to be launched in 1984. The others will be launched in that year and the succeeding two. Some will use the Atlas-Centaur launch vehicle, others the Ariane.

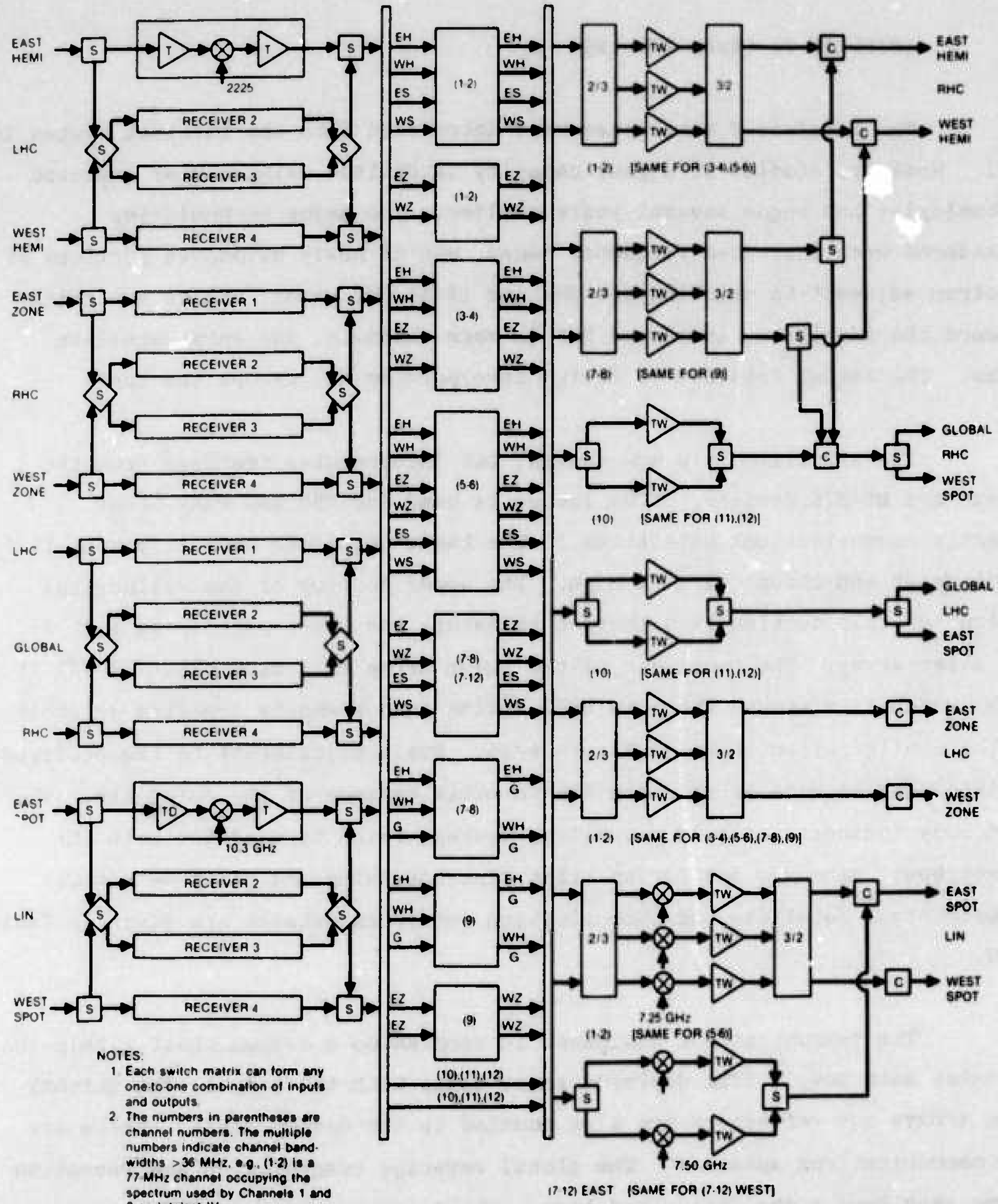
Table 4-9. Intelsat V-A Details

Satellite	Rectangular body 5.4 x 5.8 x 6.6 ft, 51 ft across tips of deployed solar arrays, 21.7 ft height to top of antenna tower ~2240 lb in orbit, beginning of life, ~1860 lb end of life Sun tracking solar arrays and NiH_2 batteries, ~1800 W beginning of life, 1280 W minimum after 7 yr Three-axis stabilization, antenna pointing accuracy $\pm 0.2^o$ in pitch and roll, $\pm 0.4^o$ in yaw
Configuration	4/6 GHz: 26 single conversion repeaters with bandwidths of 36 to 77 MHz, dual beam and dual polarization frequency reuse 11/14 GHz: 6 double conversion repeaters with bandwidths of 72 to 241 MHz, dual beam frequency reuse
Capacity	Nominal capacity in a typical operation configuration is 15,000 two-way voice circuits plus 2 television transmissions
Transmitter	4/6 GHz: 3704 to 4198 MHz Global beam: one 8.5-W TWT per repeater plus 1 spare per repeater Hemispheric beam: one 8.5-W TWT per repeater plus 1 spare per 2 repeaters Zone beam: one 4.5-W TWT per repeater plus 1 spare per 2 repeaters ERP (specified minimum): 23.5 dBW (global beam)[a]; 26 dBW (hemispheric or zone beam, 36-MHz repeaters): 29 dBW (hemispheric or zone beam, 72 to 77-MHz repeaters); 32.5 dBW (spot)[a] 11/14 GHz: 10.954 to 11.191, and 11.459 to 11.698 GHz (see text for option on F-5 and F-6) One 10-W TWT per repeater (1 for 1 redundancy for 241-MHz repeaters, 1 for 2 redundancy for 72 to 77-MHz repeaters) ERP (specified minimums): 41.1 dBW (east spot), 44.4 dBW (west spot)
Receiver	4/6 GHz: 5929 to 6423 MHz 6 active receivers with 6 spares G/T: -16.0 dB/^{o}K (global beam), -9.0 dB/^{o}K (hemispheric beam), -6.0 dB/^{o}K (zone beam), all minimum values 11/14 GHz: 14.004 to 14.498 GHz 2 active receivers with 2 spares G/T: +1 dB/^{o}K (east spot), +4.3 dB/^{o}K (west spot), both minimum values
Antenna	4/6 GHz: 2 earth coverage horns (1 transmit, 1 receive); $18^o/22^o$ beamwidths, 16.5 dB/14.5 dB minimum gains; 2 reflectors (96-in. diameter transmit, 61-in. diameter receive) with 88-horn feeds, each generating 2 hemispheric beams (21.5 dB minimum gain) and 2 smaller zone beams (24.5 dB minimum gain): zone beams each overlap a portion of one of the hemispheric beams and are separated by orthogonal polarizations; beam shapes are optimized to cover specified terminal locations; one feed horn is associated with each of the 11/14 GHz reflectors for transmission only, 5^o beamwidth, 26.2 dB minimum gain; circular polarization; minimum interbeam spatial or polarization isolation 27 dB

Table 4-9. Intelsat V-A Details (Continued)

	11/14 GHz: 2 reflectors (1 east, 1 west) each generating 1 beam for transmission and reception; west beam is 1.6° with minimum gain of 36 dB, east beam is 1.8° x 3.2° with minimum gain of 33 dB; each beam steerable over a limited portion of the earth; linear polarization; minimum interbeam spatial isolation 27 dB
Design Life	10 yr
Orbit	Synchronous equatorial, stationkeeping to ±0.1°N-S and E-W
Orbital History[b]	F-1 9 Jun 1984 Launch vehicle failure F-2 Launch scheduled late 1984 F-3 Launch scheduled 1985 F-4 Launch scheduled 1985 F-5 Launch scheduled Jan 1986 F-6 Launch scheduled May 1986 Atlas-Centaur launch vehicle (F-1 to F-4) Ariane launch vehicle (F-5 and F-6)
Developed for	Intelsat
Developed by	Ford Aerospace and Communications Corporation and subcontractors from France, West Germany, U.K., Italy, Japan, and Canada
Operated by	Intelsat

[a]3 dB larger for channel (7-8).
[b]The Intelsat V-A satellites are often called Intelsat V F-10 to F-15.



NOTES:

1. Each switch matrix can form any one-to-one combination of inputs and outputs.
2. The numbers in parentheses are channel numbers. The multiple numbers indicate channel bandwidths >36 MHz, e.g., (1-2) is a 77-MHz channel occupying the spectrum used by Channels 1 and 2 on Intelsat IV.
3. LHC/RHC = Left/right-hand circular polarization, LIN = Linear polarization.
4. Channels (7-8) and (9) may each be used on both EH and WH, or on global.
5. Spot beam antennas have 11/4 GHz diplexers (not shown).
6. Combiners after transmitters also have inputs from unillustrated transmitters.

Figure 4-15. Intelsat V-A Communication Subsystem

4.9 INTELSAT VI (Refs 185-189)

The Intelsat V satellites were introduced into the Intelsat system in 1981. However, studies of higher capacity satellites using new or improved technologies had begun several years earlier. The major technologies considered were increased frequency reuse, use of newly allocated portions of spectrum adjacent to existing 4/6-GHz and 11/14-GHz bands, active switching onboard the satellite, increased ERP in some channels, and intersatellite links. The actual Intelsat VI design incorporates all except the last.

The satellite is a new design, but incorporates features from the Leasat and HS-376 designs. (The latter is used for SBS and many other domestic communications satellites.) The basic satellite body is almost 11 ft in diameter and about 6-1/2 ft high. The upper portion of the cylindrical surface of this section is a thermal radiator; the lower portion is part of the solar array. The remainder of the solar array is a drum about 11-1/2 ft high, which fits around the main body during launch and is deployed in orbit to the configuration shown in Figure 4-16. Small adjustments to the deployed position can be made to maintain the in-orbit balance of the satellite. The main body includes a liquid propellant system, which is used for both the apogee boost maneuver and for on-orbit stationkeeping and attitude control adjustments. Satellite and communication subsystem details are given in Table 4-10.

The communications equipment is mounted on a despun shelf within the spinning main body. (The deployed array spins with the body.) The antenna feed arrays and reflectors are also mounted to the despun shelf. There are six communications antennas. The global coverage transmission and reception beams each have a dual polarized horn. The largest deployed reflector produces six 4-GHz transmit beams. The second deployed reflector provides the corresponding 6-GHz receive beams. Two of the beams provide east and west hemispheric coverage. They share a common polarization and frequency plan, their signals kept separate by the directions of the two beams. The other four are zone beams. They use the same frequencies as the hemispheric beams

but opposite polarization. The four are separated from each other by their directions, which are nominally northeast, northwest, southeast, and southwest. The southern zone beams are larger than the northern zone beams because they serve population centers in the equatorial and southern parts of the globe, which are more dispersed than those in the northern part of the globe. The hemispheric beam patterns are fixed, but the zone beams have three patterns, one for each ocean region, which can be switched in orbit. The two smaller reflectors provide steerable east and west spot beams for 11 GHz transmission and 14 GHz reception. The large hatbox shaped objects behind these two reflectors contain the more than one hundred feed horns for the 4- and 6-GHz reflectors. These complex feed arrays allow the beams to be shaped to a reasonable match to the geographic areas they serve. The feed arrays can be switched to different configurations depending on the ocean region where the satellite is located.

The communication subsystem is shown in Figure 4-17. The switch matrices in the center column of the diagram allow many different interconnections between the various beams. This flexibility allows the satellite to be in a configuration that is best suited to the traffic pattern which it is handling. Most of the switch matrices are changed infrequently by ground command. Two may be switched, according to a ground controllable pattern stored on the satellite, through several states within a 2 millisecond frame. This capability will be used in a satellite-switched TDMA (SS/TDMA) mode which will significantly increase the satellite's capacity relative to FDMA operation.

Development of the satellites began in March 1982. Critical new technology feasibility had been proved earlier through several studies sponsored by Intelsat and others. The current contract covers five satellites with options for up to eleven more. The first two launches are scheduled in 1986 on the Shuttle. Later launches will use both the Shuttle and the Ariane.

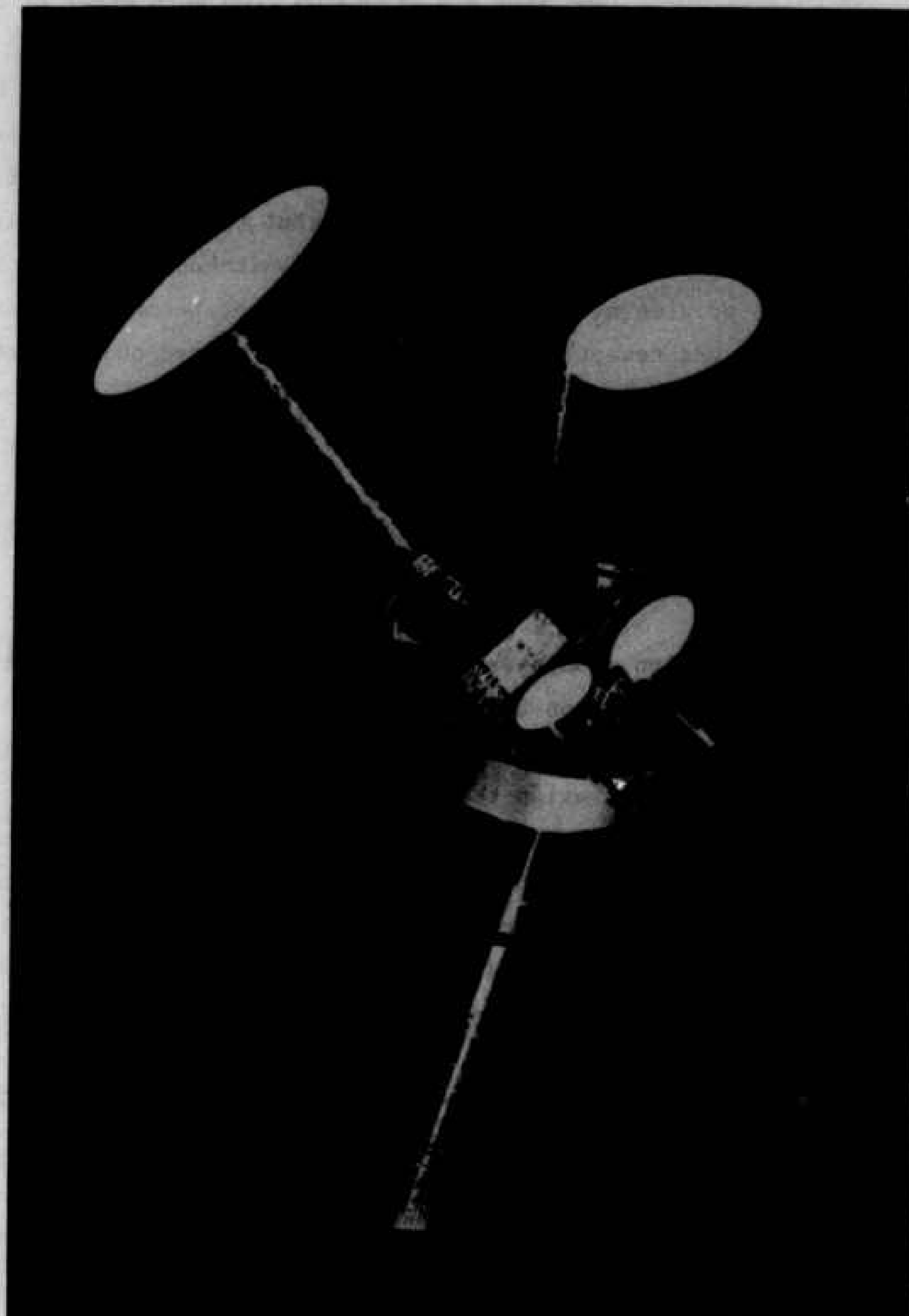


Figure 4-16. Intelsat VI Satellite

Table 4-10. Intelsat VI Details

Satellite	Cylinder, 142-in. (11.8 ft) diameter, main section ~86 in. high, deployed section ~149 in. high, overall height 464 in. (38.7 ft) ~4000 lb in orbit, beginning of life Solar cells and NiH_2 batteries, ~2200 W at end of life Spin-stabilized, gyrostat, ~30 rpm, antenna pointing accuracy $\pm 0.05^{\circ}$
Configuration	4/6 GHz: 38 single conversion repeaters with bandwidths of 36 to 72 MHz; six-fold frequency reuse except in global beams 11/14 GHz: 10 double conversion repeaters with bandwidths of 72 to 159 MHz; dual beam frequency reuse
Capacity	Nominal capacity approximately 30,000 two-way voice circuits plus 4 television transmissions
Transmitter	4/6 GHz: 3629 to 4198 MHz Global beam: one 16-W TWT per repeater Hemispheric beam: one 8.5-W TWT per repeater Zone beam: one 5.5-W TWT per SE and SW repeater, one 2-W FET amplifier per NE and NW repeater All amplifiers have one spare per two repeaters Minimum ERP: 26 dBW (global beam), 29 dBW (hemispheric and zone beams) 11/14 GHz: 10.954 to 11.191, and 11.459 to 11.698 GHz One 8.5-W TWT plus one spare per repeater ERP (minimum): 41 dBW (east spot), 44 dBW (west spot)
Receiver	4/6 GHz: 5854 to 6423 MHz 8 active receivers plus 8 spares G/T (minimum): -16 dB/^{o}K (global beam), -9 dB/^{o}K (hemispheric beam), -6 dB/^{o}K (zone beam)

Table 4-10. Intelsat VI Details (Continued)

	11/14 GHz: 14.004 to 14.498 MHz; 2 active receivers plus 2 spares G/T (minimum): +1 dB/^{o}K (east spot), +4 dB/^{o}K (west spot)
Antenna	4/6 GHz: 2 earth coverage horns; 2 reflectors (126 in. diameter transmit, 79 in. diameter receive) with 147 feed horns, each generating 2 hemispheric beams and 4 smaller reconfigurable zone beams; zone beams overlap parts of the hemispheric beams and are separated by orthogonal polarizations; beam shapes are optimized to cover specified terminal locations; each array of feed horns has four distribution networks, one for hemispheric beams and three (switchable) for the zone beams; circular polarization; minimum interbeam spatial or polarization isolation 27 dB 11/14 GHz: two reflectors (1 west, 1 east) each generating one beam for transmission and reception; 43 and 39 in. diameter; west beam is 1.6^{o} with minimum gain of 36 dB, east beam is 1.8^{o} x 3.2^{o} with minimum gain of 33 dB; each beam is steerable over a limited portion of the earth; linear polarization; minimum interbeam spatial isolation 33 dB
Design Life	10 yr
Orbit	Synchronous equatorial, stationkeeping to $\pm$0.1^{o}N-S and E-W
Orbital History	First and second launch scheduled in 1986 on Shuttle Third launch probably in 1987 Shuttle and Ariane launch vehicles
Developed for	Intelsat
Developed by	Hughes Aircraft Company; approximately 22% subcontracted to companies in U.K., France, Italy, Japan, West Germany, and Canada
Operated by	Intelsat

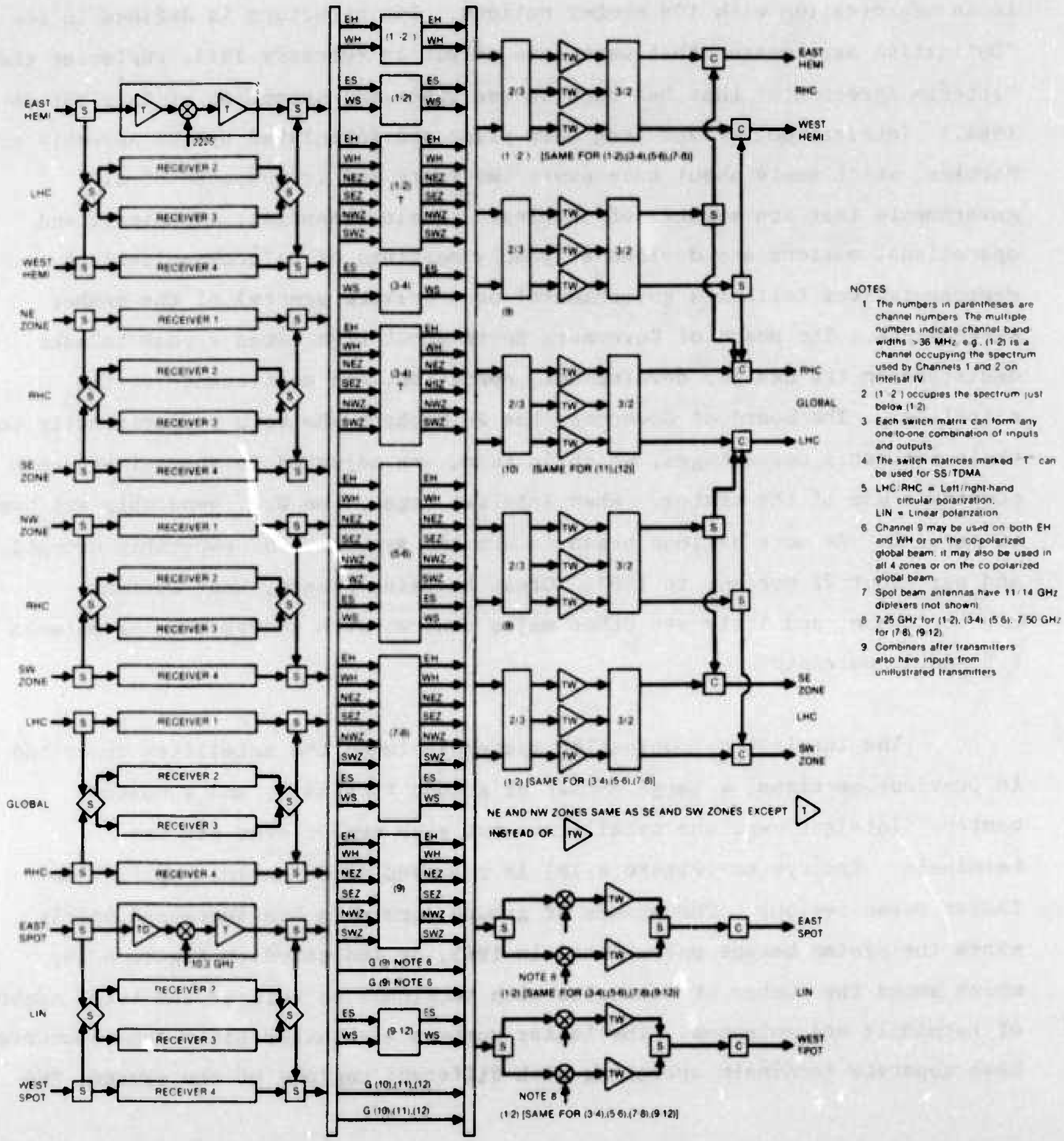


Figure 4-17. Intelsat VI Communication Subsystem

4.10 INTELSAT SYSTEM (Refs. 135, 190-221)

Intelsat (the International Telecommunication Satellite Organization) is an organization with 109 member nations. Its structure is defined in the "Definitive Agreements" that went into effect in February 1973, replacing the "Interim Agreements" that had been in use since the inception of Intelsat in 1964.* Intelsat policy and long term plans are formulated by the Assembly of Parties, which meets about once every two years and is composed of all governments that are members of Intelsat. Basic financial, technical, and operational matters are decided at yearly meetings of telecommunications representatives (either a governmental or a private agency) of the member governments. The Board of Governors meets about five times a year to make decisions on the design, development, operation, and maintenance of the satellites. The Board of Governors has 26 members who vote proportionally to their ownership percentages, which in turn, are adjusted to approximate each country's use of the system. When Intelsat began, the U.S. ownership was over 60 percent. As more nations began to use the system, U.S. ownership dropped, and was about 22 percent in 1983. Great Britain, France, West Germany, Brazil, Japan, and Italy are other major owners, with shares ranging between 2.5 and 10 percent.

The Intelsat communication system includes the satellites described in previous sections, a large number of ground terminals, and a control center. Intelsat owns the satellites, but each member owns its own terminals. The system (Figure 4-18) is composed of Atlantic, Pacific, and Indian Ocean regions. The number of ground terminals has increased yearly since the system became operational in 1965, as indicated in Figure 4-19, which shows the number of countries with terminals as well as the total number of terminals and antennas. The latter numbers are larger since some countries have separate terminals operating with different regions of the system, and

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*This change was accomplished by a change from "Consortium" to "Organization" in the full name of Intelsat.

some terminals use two or three antennas for simultaneous communications through the several active Atlantic region satellites. The overall yearly Intelsat system reliability is typically above 99.9 percent.

The ground terminal designs have evolved over the past decade, although not nearly as much as the satellite designs have. Nearly all of the current terminals conform to "standard designs," the basic specifications of which are given in Table 4-11. The primary difference between the terminals is in the amount of electronic equipment they have, which depends on the number and capacity of the communication links that must be handled simultaneously. Also, the various terminal suppliers use different equipment and designs to attain the "standard" performance. The relatively large antenna size of the standard A terminal has resulted because the early Intelsat satellites (through type III) were power limited. Thus, system capacity was a function of ground antenna gain, so large antennas were used. Now in many operating modes the satellites are bandwidth limited. Therefore, Intelsat has adopted a specification for a smaller standard B terminals. The B terminals are suited to locations with low traffic requirements and use single channel per carrier modulation. The B terminals are commonly used in domestic communications systems which use leased Intelsat transponders. The standard C terminals communicate with the 11- and 14-GHz transponders on the Intelsat V satellites. In these bands, rain attenuation is significant and must be accounted for in the terminal specification. Some standard C terminals may have two antennas separated by 10 to 20 mi in order to overcome rain attenuation by space diversity. A smaller antenna (~ 16 ft diameter) for domestic communications is possible under the new standard D definition. Another type of small terminal, standard E, will come into use in 1985 when Intelsat begins a point-to-point international data transmission service.

The Intelsat system also has eight telemetry, tracking, and command (TT&C) terminals. These terminals continually monitor all communication downlinks for satellite problems or evidence of out-of-specification conditions in any transmission. They are located in Maine, Hawaii, Australia,

Italy, Cameroon, Brazil, France, and Japan, allowing every satellite to be visible to at least two terminals. They are under the direction of the Intelsat Operations Center in Washington, D.C.

Intelsat handles telephone, telegraph, data, and television traffic. Telephone is the major portion of the traffic, accounting for about 85 percent of Intelsat revenues. Television accounts for about 10 percent of the monthly revenues. By the beginning of 1983, there were about 30,000 telephone circuits in use. Of these circuits, 66 percent were in the Atlantic region, 10 percent in the Pacific region, and 24 percent in the Indian Ocean region. The growth of traffic in the system is indicated in Figure 4-20.

This traffic is the international use of the Intelsat satellites. Beginning in 1974, Intelsat leased spare satellite capacity for use in domestic satellite communication systems (see Section 7.19). Since the end of the 1970s this service has rapidly increased in popularity. At the beginning of 1983 about two dozen countries were leasing Intelsat capacity and more than a dozen others had plans to do so. Because of this rapid growth, in 1982 Intelsat changed its policy from providing this service via excess satellite capacity to planning future satellite capacity to meet the expected demand.

Satellite capacity is allocated to the terminals by preassignment and demand assignment. Preassignments are made by the Operations Center for long duration use, and preassigned links are either single channel per carrier (SCPC) or multiplexed voice circuits in certain standard sizes between 24 and 972 circuits. Television transmissions are preassigned. Demand assignment, introduced in 1971, used the SPADE technique.* With this technique a satellite transponder is divided into 400 channel pairs, each pair handling one voice conversation by means of two SCPC transmissions. Each SPADE terminal has a small computer that selects a channel pair at the time a link is required. Immediately after use, the pair is released and returned to the

*Single channel per carrier, Pulse code modulation, multiple Access, Demand-assigned Equipment.

pool of channels available to all terminals. Demand assignment is used for traffic peaks above preassigned capacity or between terminals with no preassigned circuits.

All SCPC transmissions are quadraphase shift keying (QPSK) modulated at 64 kbps, and handle either a single voice circuit or digital data at rates up to 56 kbps or multiplexed lower rate data streams. The multiple-voice-circuit transmissions are frequency multiplexed and use frequency modulation. Except for a few large links that occupy a whole transponder, most transmissions share satellite transponders by means of frequency division multiple access (FDMA). Television transmissions use frequency modulation with either one or two transmissions per transponder.

In the second half of 1978, Intelsat began time division multiple access (TDMA) field tests with five terminals in the Atlantic region accessing one transponder at 60 Mbps with QPSK modulation. Since 1981 there has been limited operational use of TDMA on Intelsat V satellites. The transmission rate is 120.8 MBPS and uses 72-MHz bandwidth transponders. Intelsat V-A satellites have some changes to provide better response to TDMA transmissions, as system use increases. Large scale use of TDMA will come in the late 1980s on Intelsat VI satellites. These satellites have a dynamic switching capability, which can reconfigure the antenna beam interconnections on a TDMA burst to burst basis (SS/TDMA) to maintain a high level of connectivity between TDMA ground stations in different beams. Using these satellites, about half of Intelsat's traffic will use TDMA by the early 1990s. Digital speech interpolation (DSI) will be used on TDMA voice circuits to provide up to 2-1/2 times more circuits per transponder compared to non-DSI FDMA transmissions.

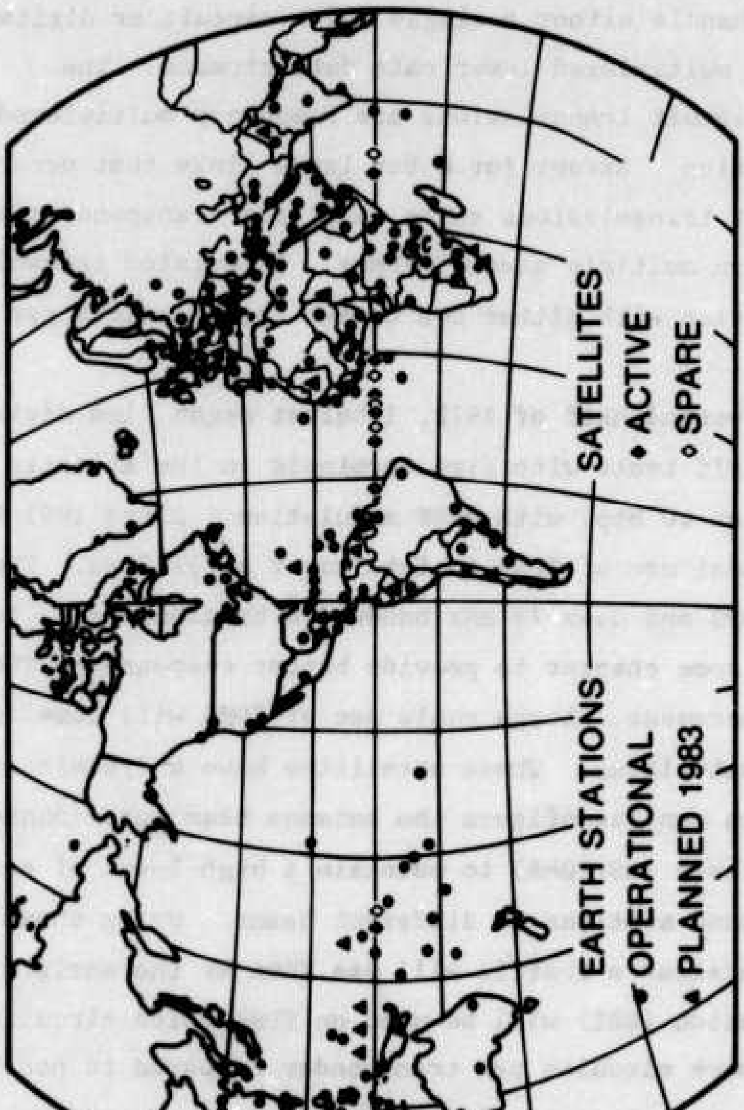

Figure 4-18. Intelsat System

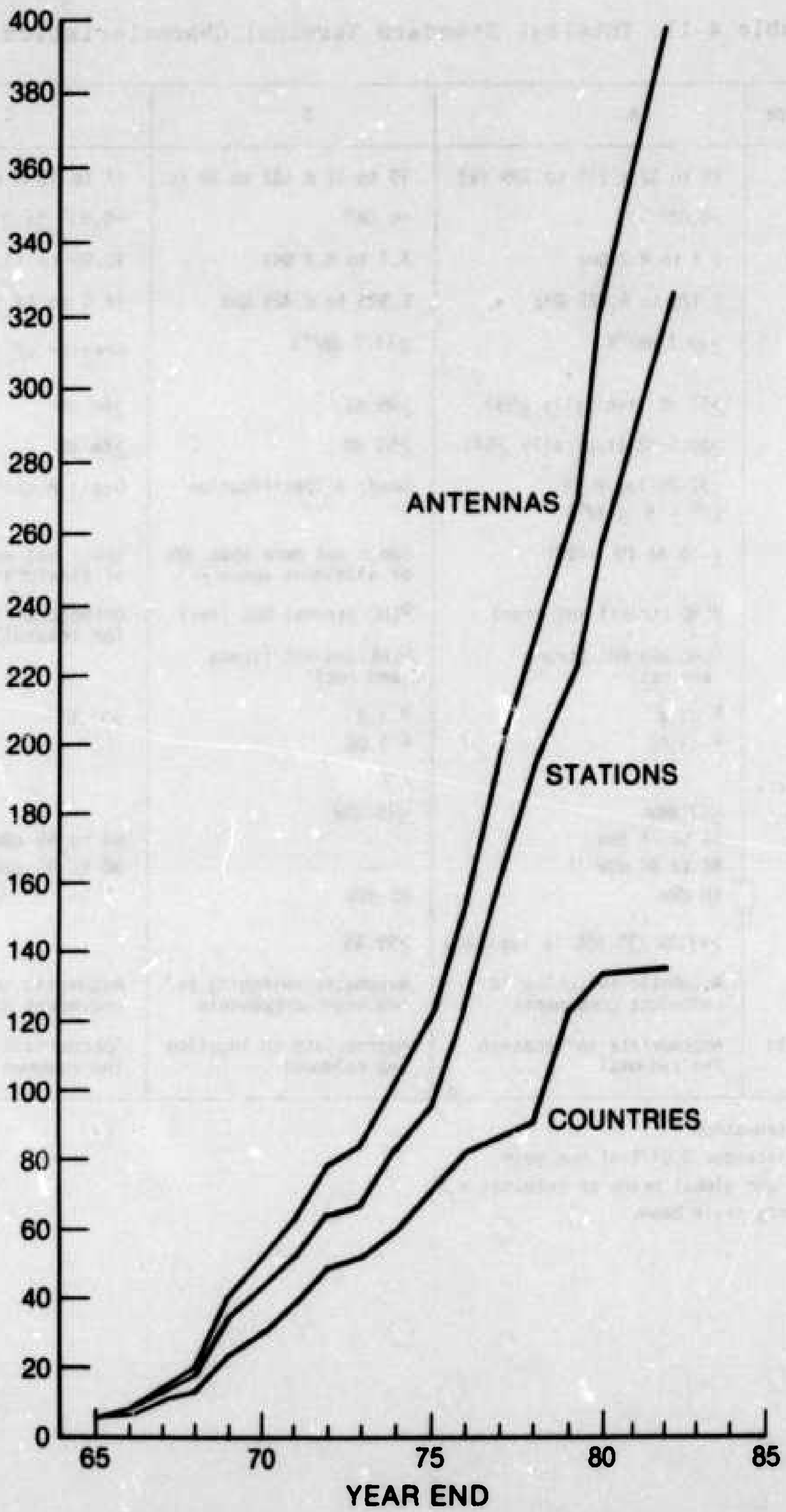

Figure 4-19. Intelsat Ground Terminals

Table 4-11. Intelsat Standard Terminal Characteristics

Terminal Type	A	B	C
Antenna Diameter	29 to 32 m (95 to 105 ft)	10 to 12 m (33 to 39 ft)	17 to 18 m (56 to 59 ft)
Pointing Accuracy	$\sim 0.02^{\circ}$	$\sim 0.06^{\circ}$	$\sim 0.01^{\circ}$ to 0.02°
Transmit Frequency	3.7 to 4.2 GHz	3.7 to 4.2 GHz	10.95 to 11.7 GHz
Receive Frequency	5.925 to 6.425 GHz	5.925 to 6.425 GHz	14.0 to 14.5 GHz
G/T	≥ 40.7 dB/°K	≥ 31.7 dB/°K	Greater of $\left\{ \begin{array}{l} 39 \text{ dB/°K} + L_1{}^a \\ 29.5 \text{ dB/°K} + L_2{}^a \end{array} \right.$
Receive Gain	≥ 57 dB (typically ≥ 59)	≥ 49 dB	≥ 64 dB
Transmit Gain	≥ 60.5 dB (typically ≥ 64)	≥ 53 dB	≥ 66 dB
Sidelobes	$\leq 32-25 \log \theta$ dB ($1^{\circ} \leq \theta \leq 48^{\circ}$)	Goal: A specification	Goal: A specification
	≤ -10 dB ($\theta > 48^{\circ}$)	Spec: not more than 10% of sidelobes above A	Spec: not more than 10% of sidelobes above A
Polarization	[b]LHC (trans) RHC (rec)	[b]LHC (trans) RHC (rec)	Orthogonal linear states for transmit and receive
	[c]LHC and RHC (trans and rec)	[c]LHC and RHC (trans and rec)	
Axial Ratio	[b] ≤ 1.4 [c] ≤ 1.06	[b] 1.4 [c] 1.06	≥ 31.6
ERP (channel/carrier)			
- single-voice	≤ 63 dBW	≤ 70 dBW	--
- 24-voice	74 to 76 dBW	-	64 to 69 dBW
- 972-voice	88 to 90 dBW	--	80 to 85 dBW
- TV	88 dBW	85 dBW	--
Availability	$\geq 99.8\%$ (99.95% is typical)	$\geq 99.8\%$	
Redundancy	Automatic switching to redundant components	Automatic switching to redundant components	Automatic switching to redundant components
Environmental Limits	Appropriate to location (no radomes)	Appropriate to location (no radomes)	Appropriate to location (no radomes)

[a] L_1 = clear sky attenuation.
L_2 = attenuation exceeded 0.017% of the year.
[b]Intelsat IV, IVA, and global beams of Intelsat V.
[c]Intelsat V frequency reuse beams.

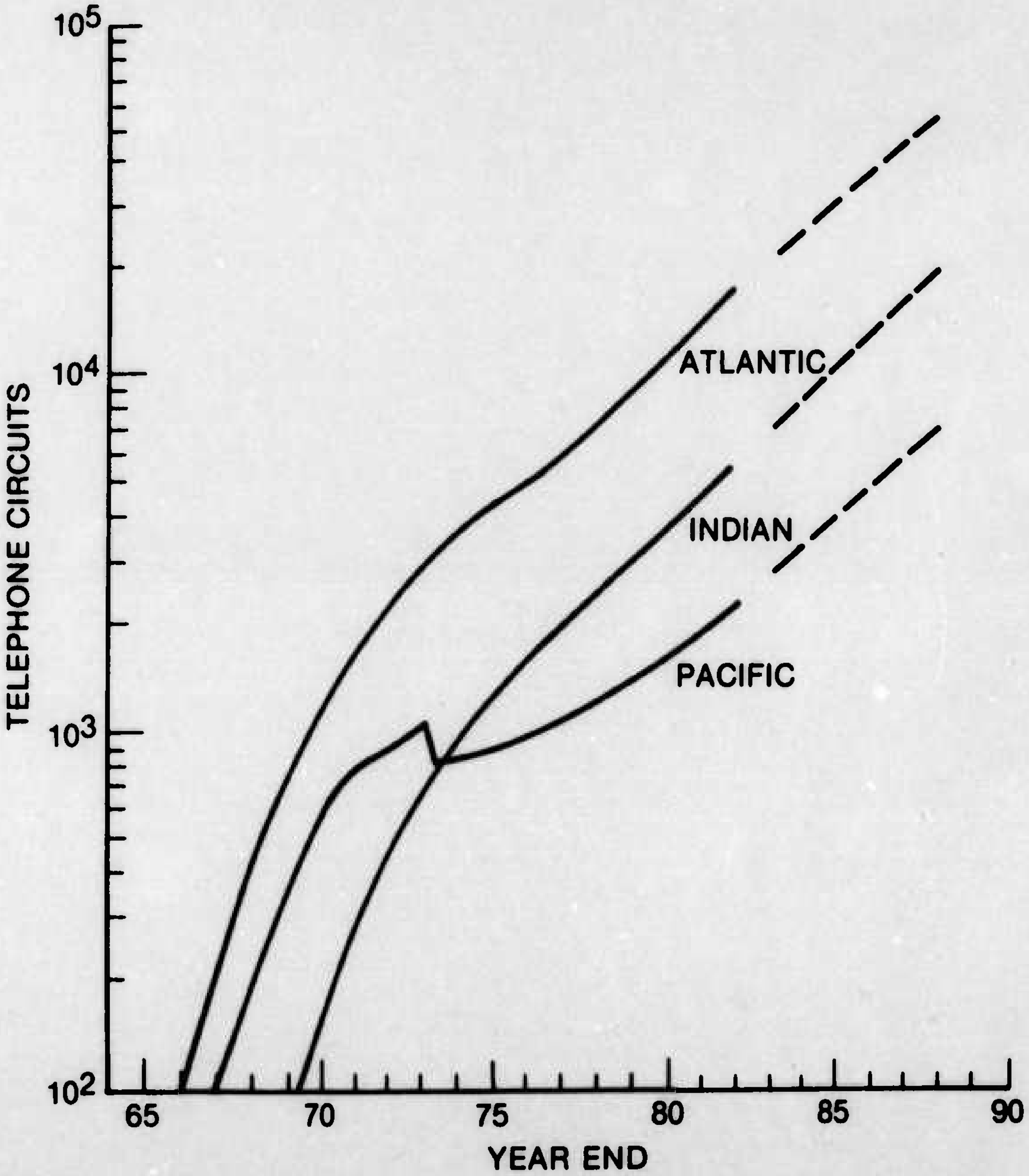

Figure 4-20. Intelsat Traffic

5. MILITARY SATELLITES

The first communication satellite experiments were conducted by the U.S. Army. Since then the U.S. Department of Defense has continued to develop technology and to deploy operational satellites. This section describes the various communication satellites developed by DoD, joint programs with Britain and the North Atlantic Treaty Organization (NATO), and the British military satellites (Skynet). The section ends with a description of the Defense Satellite Communications System (DSCS). The satellites developed by the MIT Lincoln Laboratory for DoD (the LES series), being experimental types, are described in Section 3.

Within the U.S., Government policy is to establish and maintain distinct military communication satellite systems to satisfy unique and vital national security needs that cannot be met by commercial facilities. On the other hand, the Government will use commercial satellites whenever links of the required type and quality can be obtained in a timely manner at reasonable cost. In general, military command and control circuits are routed through military satellites, but administrative and logistics circuits may use commercial satellites. Differences between military and commercial systems occur because of unique military requirements such as protection against jamming, secure command and telemetry links, flexibility to rapidly extend service to new regions of the globe and to reallocate system assets, hardening of satellites and terminals to resist attacks, and satellite operation continuing through lengthy periods (e.g., several weeks) without command and telemetry support.

5.1 IDCSP (Refs. 222-225)

No U.S. military communication satellites were launched between October 1960 (Courier 1B*) and June 1966. Courier was a relatively simple program for early experimental use. Concurrently, in April 1960, the Advanced Research Projects Agency (ARPA) began the Advent program (Refs. 14, 226-227) to provide an operational military communication satellite. Advent was to be a three-axis-stabilized, stationkeeping, synchronous altitude satellite with sun-oriented solar arrays and an earth coverage antenna. The communications equipment was to have four repeaters, each with a capacity for 12 one-way voice links or one spread-spectrum voice link. In addition, a secure command system was intended. A number of problems resulted because the concept was far beyond available technology. The satellite weight grew while the Centaur launch vehicle program slipped. After several major reviews, the program was canceled in May 1962.

At that time two programs were recommended. One was to use proven technology to develop simple satellites to be placed in random polar orbits at about 5000 mi altitude. The satellites were to be launched seven at a time using the proven Atlas-Agena launch vehicle. The second program was for later deployment of synchronous altitude stationkeeping satellites. The programs later were known as the Initial and Advanced Defense Communication Satellite Programs (IDCSP and ADCSP).

IDCSP did not proceed quickly because of several nontechnical factors. One delay was caused by lengthy discussions with Comsat Corporation concerning whether or not they could provide the satellite services required by DoD. By fall 1964, when IDCSP entered the final design and fabrication phase, the Titan IIIC appeared to be a feasible launch vehicle. Therefore, the satellite designs were made compatible with either a medium altitude polar orbit (Atlas-Agena launch vehicle) or a near-synchronous altitude equatorial orbit (Titan launch vehicle). The commonality requirement was dropped after

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*See Section 3.3.

the first successful Titan IIIC launch in June 1965, when it was chosen as the IDCSP launch vehicle.

The basic design principle for IDCSP (Figure 5-1) was simplicity. By using spin-stabilized satellites in subsynchronous orbits, neither stationkeeping nor active altitude control was required. The random nature of the individual satellite orbits provided automatic replacement of failed satellites with acceptable outages. No command system was used because of previous experiences - command system failures terminated Courier and Telstar 1 operations, and command system problems contributed to the cancellation of Advent. Telemetry was not required but was added since performance data would be very useful. Each satellite had two TWTs, and an onboard sensor switched from one to the other upon detecting a failure. The two TWTs were of different designs to reduce the chance of a common failure mode. Design details are given in Table 5-1, and Figure 5-2 is a block diagram of the communication subsystem.

The first IDCSP satellites were launched in June 1966. Further satellites were launched in 1967 and 1968; two launches had a full load of eight IDCSP satellites and the other had three in addition to three other satellites. In 1967 increasing military activity in Vietnam led to the establishment of an operational communication link using IDCSP. In this link, high speed digital data were transmitted from Vietnam to Hawaii via one satellite and from there to Washington, D.C. via another satellite.

By the time of the 1968 launch, the system was declared operational, and the name changed to Initial Defense Satellite Communication System (IDSCS). The satellites operated for periods ranging from a few thousand hours to more than 70,000 hours (8 yr). The satellites each have a device that was supposed to deactivate them approximately six years after launch. Several satellites were turned off in this manner, although others continued to operate well beyond six years. The overall satellite reliability was much beyond the original expectations; specifically, the actual mean time before

failure (MTBF) achieved is more than double the three-year goal for design life. Three of the satellites were still being used in early 1976 to supplement the DSCS II satellites. By mid-1977 only one was still useable.

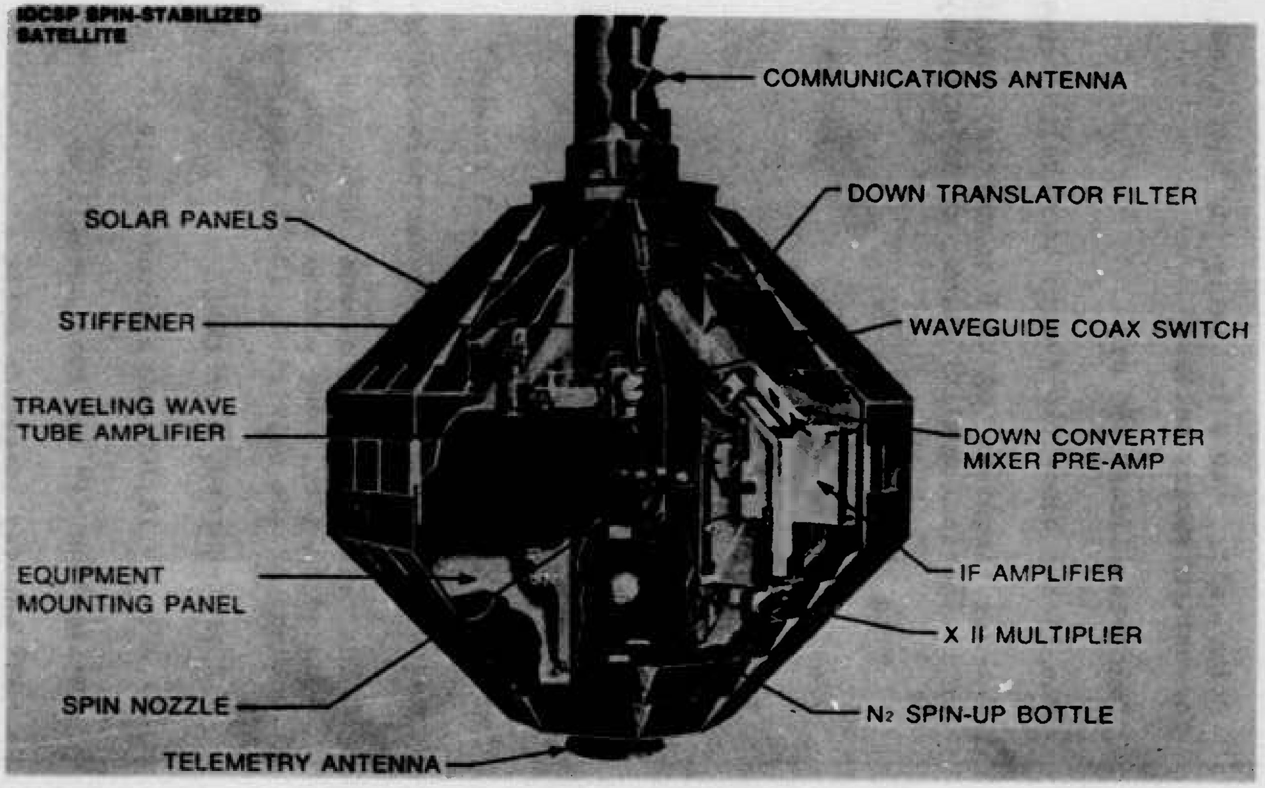

Figure 5-1. IDCSP Satellite

Table 5-1. IDCSP Details

Satellite	Polyhedron, 36-in. diameter, 32 in. high 100 lb (GGTS[a] 104 lb, DATS[b] 150 lb) Solar cells, ~40 W initially (no batteries, no operation during eclipse) Spin-stabilized, 150 rpm
Configuration	One 20-MHz bandwidth double conversion repeater
Capacity	Two-way circuits: up to 5 commercial quality voice, or 11 tactical quality voice, or 1550 teletype ~1 Mbps digital data
Transmitter	7266.4 to 7286.4 MHz 2 TWTs (1 on, 1 standby) 3-W output, 7-dBW ERP maximum
Receiver	7985.1 to 8005.1 MHz 10-dB noise figure
Antenna	2 biconical horns (1 transmit, 1 receive) $28^\circ \times 360^\circ$, 5-dB gain, circular polarization DATS: electronically despun, antenna elements are mounted on a cylinder placed along the spin axis at one end of the satellite, 10-dB additional gain
Design Life	1.5 yr required, 3-yr goal
Orbit	17,800- to 18,700-nmi altitude range Inclination $<1^\circ$ for most satellites $\sim 30^\circ$ per day longitude drift
Orbital History	1-7: Launched 16 Jun 1966 Eight unnumbered satellites lost in a launch vehicle failure 26 Aug 1966

Table 5-1. IDCSP Details (Continued)

	8-15: Launched 18 Jan 1967 16-18: Launched 1 Jul 1967 19-26: Launched 13 Jun 1968 GGTS: Launched with 1-7 DATS: Launched with 16-18 Operating lifetimes (excluding GGTS & DATS): 5 1 yr operation before failure 1 1-2 yr operation before failure 2 2-3 yr operation before failure 2 3-4 yr operation before failure 2 4-5 yr operation before failure 2 5-6 yr operation before failure 2 6-7 yr operation before failure 1 7-8 yr operation before failure 6 Turned off by the onboard timer after 6-1/2 to 8 yr operation 3 Operated 9-10 yr Overall MTBF ~6 yr Titan IIIC launch vehicle
Developed for	SAMSO
Developed by	Philco (now Ford Aerospace and Communications Corporation)
Operated by	Defense Communications Agency

[a]Gravity Gradient Test Satellite.
[b]Despun Antenna Test Satellite.

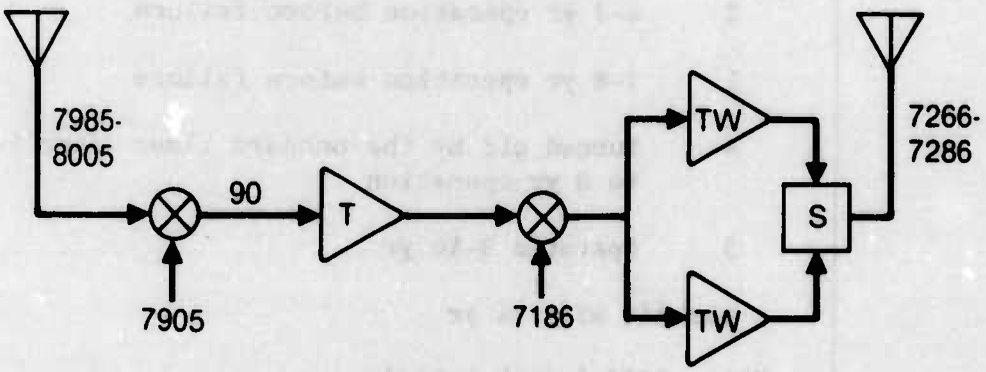

Figure 5-2. IDCSP Communication Subsystem

5.2 TACSAT (Refs. 223-224, 228-229)

The IDCSP satellites and the advanced satellites that were to follow IDCSP were all intended for strategic communications. Strategic communication terminals basically include large antenna fixed or transportable ground stations or large shipborne equipment. Tacsat was designed for a complementary function, namely, to operate with small land-mobile, airborne, or shipborne tactical terminals.

The Lincoln Experimental Satellites (LES-1 to -6) were predecessors to Tacsat and were used to investigate various aspects of tactical communications. Strategic military communication satellites typically use frequencies between 7 and 8.5 GHz. At these frequencies, directional antennas are required and these antennas have several drawbacks in tactical use. One drawback is the problem of accurate pointing, especially from aircraft. The LES satellites proved that UHF (~300 MHz) communication is possible with terminals having simple, low gain (wide beamwidth) antennas. Tacsat (Figure 5-3) was designed with both UHF and X-band (8-GHz) capabilities and crossover modes (UHF receive and X-band transmit, or vice versa) to allow operation with a wide variety of terminals. Figure 5-4 is a communication subsystem block diagram.

The requirements for Tacsat resulted in a number of design features not found in previous communication satellites. Nearly 1 kW of prime power was required for the high power transmitters, which meant a very large cylindrical body to provide the required solar cell area. Tacsat was spin-stabilized like all previous communication satellites. However, because of the large antenna structure and launch vehicle fairing constraints, it did not spin about the axis having the maximum moment of inertia. This was a potentially unstable condition that was controlled by special stabilizing elements. The stabilization worked in orbit, although at times a one-deg nutation occurred, apparently the result of destabilizing forces that were greater than expected. The stabilization techniques developed for Tacsat and

called "gyrostat" by the manufacturer were refined and applied to many subsequent satellites. Other design features of Tacsat are given in Table 5-2.

Tacsat was launched in February 1969. Because of funding limitations, no flight model was assembled and the qualification model was the one launched. On-orbit testing was done with a large variety of terminals including large ground stations, mobile ground stations, aircraft, and ships. Some multiple access testing was done. Tacsat was used for operational support of Apollo recovery operations, connecting the aircraft, their aircraft carrier, and ground stations. Military use, especially of the UHF band, was extensive. Operations continued until an attitude control failure at the end of 1972.

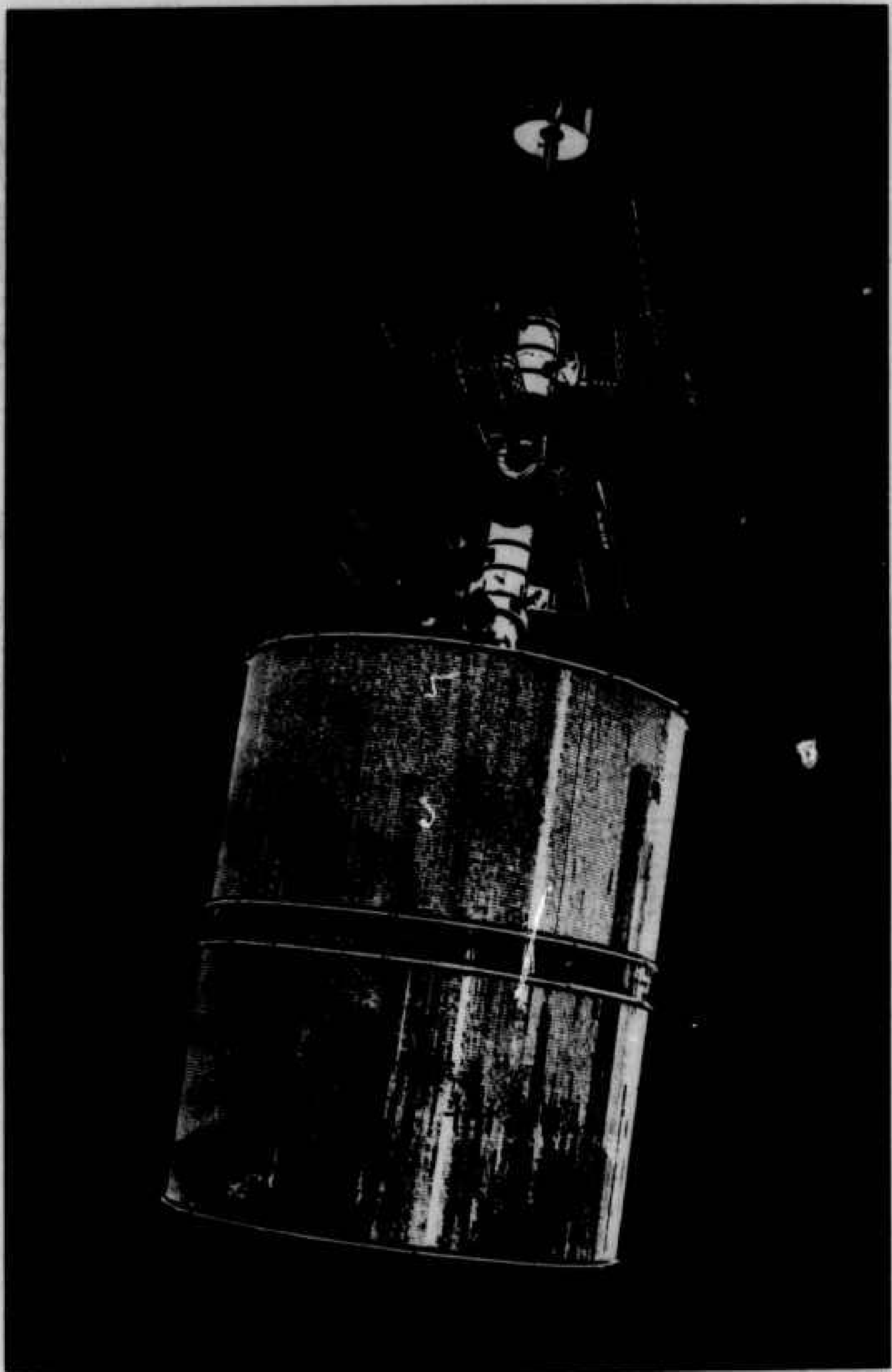

Figure 5-3. Tacsat Satellite

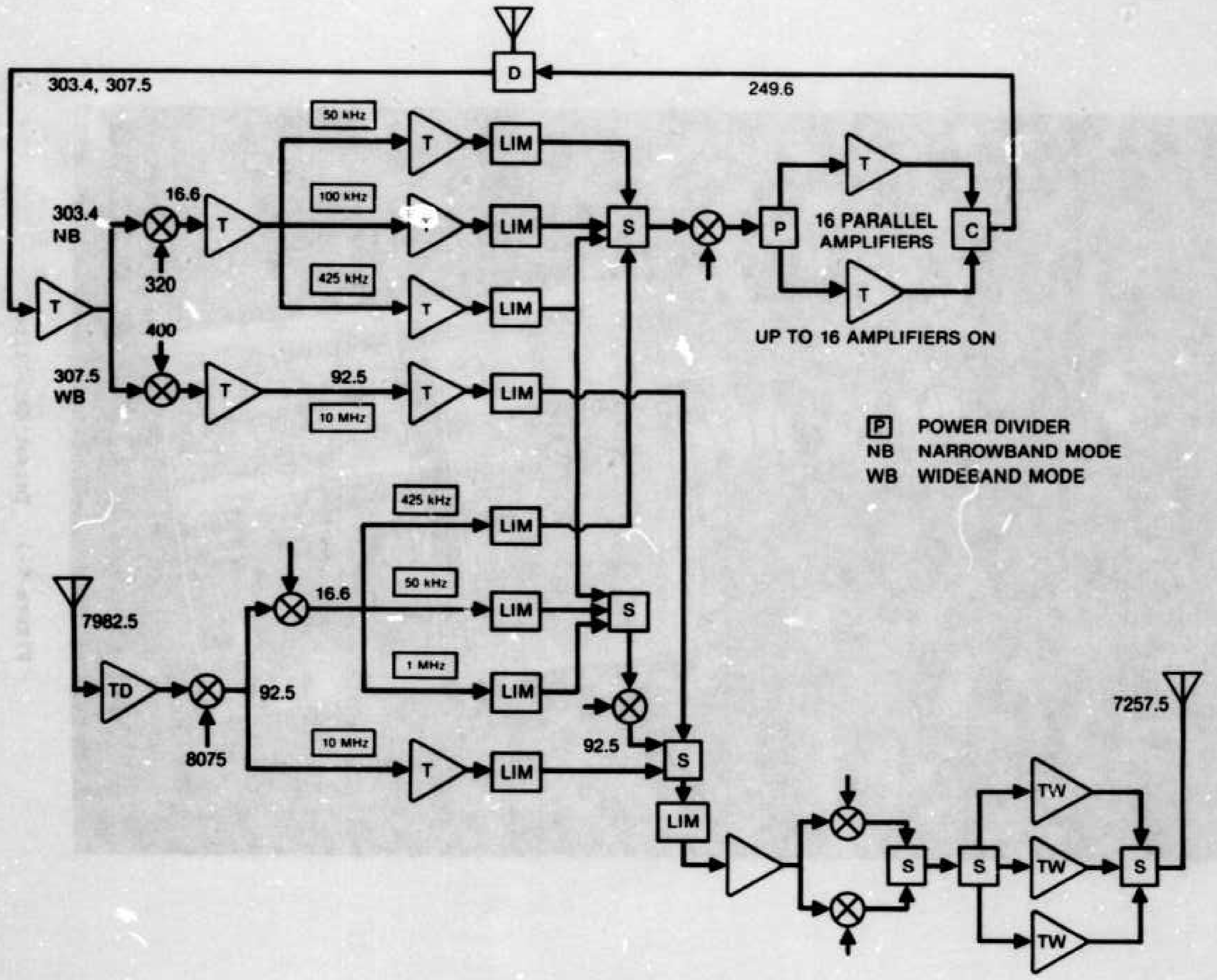

Figure 5-4. Tacsat Communication Subsystem

Table 5-2. Tacsat Details

Satellite	Cylinder, 9-ft diameter, 11 ft high, overall height 25 ft
	1600 lb in orbit, beginning of life
	Solar cells and NiCd batteries, 980 W
	Spin-stabilized, gyrostat, 54 rpm
Configuration	Multiple channels, 50-kHz to 10-MHz bandwidths
Capacity	UHF: About 40 vocoded voice or several hundred teletype circuits to a terminal with 0-dB antenna gain
	X-band: About 40 vocoded voice or 700 teletype circuits to a terminal with a 3-ft antenna
Transmitter	249.6 and 7257.5 MHz
	UHF: All solid state, 16 parallel transistor amplifiers, up to 16 on at a time (nominal 13 on), 18.5 W per amplifier, 230 W maximum out of combiner
	X-band: 3 TWTs, 2 on at a time, 20 W per TWT, 30 W out of combiner
Receiver	303.4, 307.5, and 7982.5 MHz
	UHF: Transistor amplifiers 3.7-dB noise figure
	X-band: Tunnel diode preamplifier 6.9-dB noise figure
Antenna	UHF: 5 bifilar helices, 17.1-dB transmit gain, 17.6-dB receive gain
	X-band transmit: Horn, 18.4-dB gain, 19° beamwidth
	X-band receive: Horn, 19.3-dB gain, 17° beamwidth
Design Life	2.4 yr estimated life
Orbit	Synchronous equatorial, approximately 180°W longitude
Orbital History	Launched 9 Feb 1969
	Operated until Dec 1972
	Titan IIIC launch vehicle
Developed for	SAMSO
Developed by	Hughes Aircraft Company
Operated by	Air Force Communications Service

5.3 SKYNET I AND NATO II (Refs. 223-224, 230-233)

The Skynet (United Kingdom) and NATO satellite programs were both a result of a U.S. invitation to certain nations to participate in the use of U.S. defense communication satellites. In 1966 the U.K. indicated an interest in participation, but the IDCSP satellites could not satisfy their requirements. The primary difference was the need to service both ground stations with large antennas and shipborne terminals with smaller antennas. In late 1966 the U.S. and U.K. signed an agreement whereby the U.S. would develop satellites that would satisfy U.K. needs. The satellites were to be interoperable with the IDCSP system and the program was initially called IDCSP/A (for augmentation). This program is now known as Skynet. NATO decided to participate directly in the use of IDCSP satellites, and operated two IDCSP ground stations from 1967 to 1970. That period was used to gain experience prior to operation of a NATO satellite.

The Skynet (Figure 5-5) and NATO satellites were nearly identical and were derived from the IDCSP design, but there were certain notable improvements from IDCSP. Table 5-3 gives details of their designs. The Skynet and NATO satellites were placed into a synchronous orbit and had a stationkeeping capability. They had a despun antenna providing increased gain, relative to IDCSP, and both 2- and 20-MHz channels. These features allow operation with both large and small terminals. Figure 5-6 is a block diagram of the communication subsystem. Also, the satellites were larger than IDCSP satellites and had a command system. The only significant difference between the two satellites was the antenna pattern. The Skynet antenna provided a relatively uniform earth coverage pattern centered at the equator. The NATO antenna pattern was shaped to cover only the NATO nations, from the eastern coast of North America to Turkey.

The first Skynet satellite was launched in November 1969 and operated for several years with a variety of terminals. Antenna sizes varied from 42 ft at the master ground station to 3.5-ft shipborne terminals. The second

Skynet satellite did not achieve the intended synchronous orbit because of failure of the apogee motor.

The NATO satellites were designated NATO IIA and IIB, with NATO I referring to the period of operations during which the IDCSP satellites were used. NATO IIA and IIB were launched in March 1970 and February 1971. The former was used for communications between NATO headquarters and the capitals of NATO member countries. Planned use with shipborne terminals was delayed because other traffic occupied nearly all of the satellite capacity. NATO IIB was originally an orbiting spare that was used in tests of new ground stations. The communications traffic was transferred to it after NATO IIA failed. Communications traffic was transferred to NATO IIIA in April 1976, and NATO IIB was turned off in August 1976.

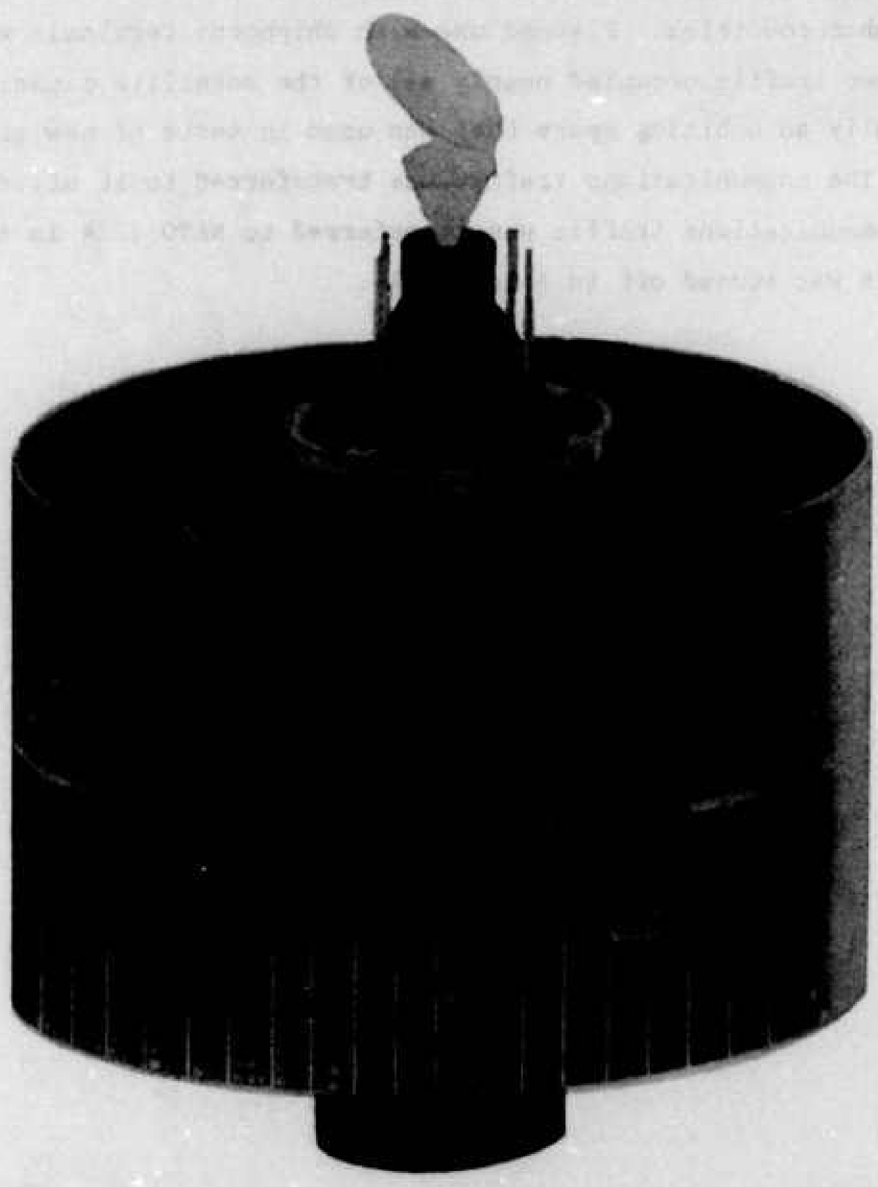

Figure 5-5. Skynet I Satellite

Table 5-3. Skynet I and NATO II Details

Satellite	Cylinder, 54-in. diameter, 32 in. high, overall height 62 in.
	285 lb in orbit
	Solar cells and NiCd batteries, 78 W
	Spin-stabilized, 90 rpm
Configuration	One 2- and one 20-MHz bandwidth double conversion repeater
Transmitter	7257.3 to 7259.3 and 7266.4 to 7286.4 MHz
	2 TWTs (1 on, 1 standby), 3.5-W output
	Skynet: 14.4-dBW ERP per channel, edge of earth
	NATO: 11-dBW (2-MHz channel) and 19-dBW (20-MHz channel) ERP, edge of coverage
Receiver	7976 to 7978 and 7985.1 to 8005.1 MHz
	Redundant receivers (1 on, 1 standby)
	8.8-dB noise figure
Antenna	Skynet: Mechanically despun horn, earth coverage 18.5-dB peak gain
	NATO: Mechanically despun horn, NATO area coverage (North American east coast to eastern Turkey)
Design Life	5 yr (3 yr MMD[a])
Orbit	Synchronous equatorial (inclination $\leq 3^{\circ}$)
	Skynet: 49 $\pm 3^{\circ}$E longitude
	NATO: 18 $\pm 3^{\circ}$W longitude (IIA), 26 $\pm 3^{\circ}$W longitude (IIB)
Orbital History	Skynet IA: Launched 21 Nov 1969; operated 36 months
	Skynet IB: Launched 19 Aug 1970; apogee motor failure left satellite in synchronous transfer orbit
	NATO IIA: Launched 20 Mar 1970; operated 26 months
	NATO IIB: Launched 3 Feb 1971; operated until Aug 1976
	Delta launch vehicle
Developed for	SAMSO, acting for United Kingdom and NATO
Developed by	Philco (now Ford Aerospace and Communications Corporation)
Operated by	U.S./U.K. and U.S./NATO

[a]Mean mission duration

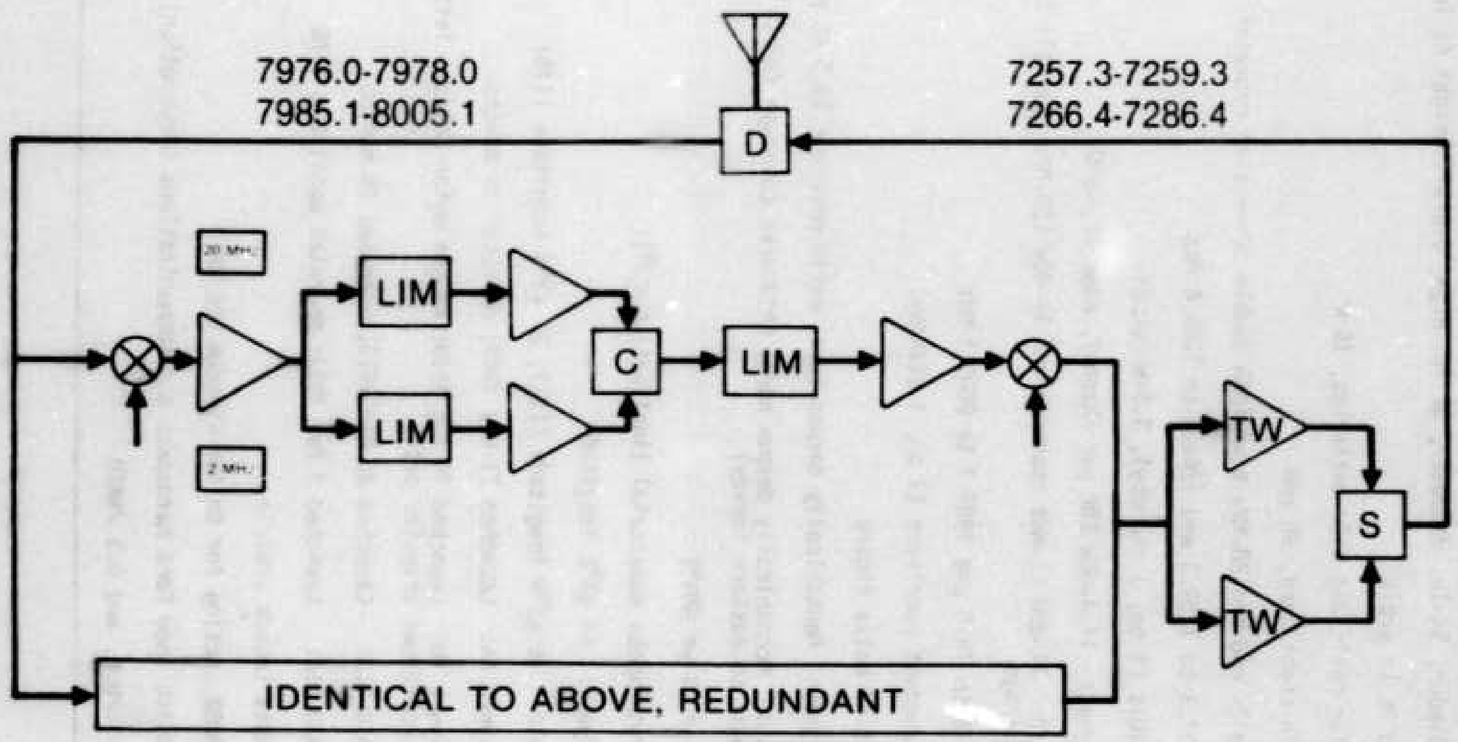

Figure 5-6. Skynet I Communication Subsystem

5.4 DSCS II (Refs. 234-243)

The IDCSP satellites were the Phase I space segment of the Defense Satellite Communication System (DSCS). System testing began immediately after the first launch in 1966, and the Pacific part of the DSCS was switched to operational status a year later. The experiences of Phase I demonstrated that satellite communications could satisfy certain DoD needs. Therefore, in June 1968, DoD decided to proceed with development of advanced satellites for DSCS Phase II.

The DSCS II satellites* are significantly different from the IDCSP satellites. The DSCS II satellites have a command subsystem, attitude control and stationkeeping capability, multiple communication channels with multiple access capability, and some measure of hardening; IDCSP had none of these features. However, the DSCS II design is compatible with modified Phase I ground terminals as well as new terminals specifically built for Phase II.

The Phase II satellites (Figure 5-7) have a dual spin configuration. The outer section (which includes the cylindrical solar array, much of the structure, and an equipment platform) is spun to stabilize the satellite. The inner section (containing all the communications equipment and antennas) is isolated from the outer section by a motor and bearing assembly. The motor despins the inner section so that the antennas are always pointed at the earth. The satellite has four antennas, two parabolic reflectors and two horn antennas. Table 5-4 gives details of the DSCS II satellite design.

The DSCS II communication subsystem (Figure 5-8) has four channels with the following characteristics:

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*Formerly known as the 777 satellites because their development was called Program 777.

Channel	Bandwidth (MHz)	Receive Antenna	Transmit Antenna
1	125	Earth coverage	Earth coverage
2	50	Narrowbeam*	Earth coverage
3	185	Narrowbeam*	Narrowbeam*
4	50	Earth coverage	Narrowbeam*

This selection of channels allows the flexibility to handle a wide variety of links and to interface with many different sizes of terminals. The subsystem includes tunnel diode preamplifiers, single frequency conversion, TDAs, and driver and high power TWTs. The TDAs can be switched to various gains to allow either linear or saturated operation of each channel. All the communication subsystem assemblies are redundant.

The DSCS II satellites are launched in pairs. The first launch was in November 1971. Initially both satellites operated properly, but major problems occurred in each in the year following launch, and they ceased to operate in September 1972 and June 1973. Analyses of these problems provided the basis for design modifications for the following satellites. The next pair was launched in December 1973. One failed in 1976; the other is still operating. The third pair was launched in May 1975 but, because of a launch vehicle failure, they did not achieve a useful orbit.

Late in 1974, a set of six replenishment satellites was ordered by the Government. Later, a third group of four satellites was ordered. These four satellites have 40-W TWTs instead of 20-W TWTs, and all ten have one narrowbeam antenna defocused to provide area coverage (6° nominal beamwidth). These ten satellites are being launched to establish and maintain an orbital system of four active and two spare satellites. The first pair (satellites 7 and 8) was launched in May 1977. The next pair was launched in March 1978, but was lost as the result of a launch vehicle malfunction.

*Or area coverage (on satellites 7 to 16).

Satellites 11 and 12 were launched in December 1978 and satellites 13 and 14 were launched in November 1979. Satellite 16 was launched in October 1982 with the first DSCS III.

The DSCS satellites are operated at four orbital locations: Atlantic, East Pacific, West Pacific, and Indian Ocean. In 1985 the respective active satellites in these locations are 14, the DSCS III, 13 and 12; the spares are 16, 11, and 8. Satellite 7 has been taken out of service because both narrowbeam/area coverage TWTs failed. Satellite 4 has been taken out of service and declared experimental.

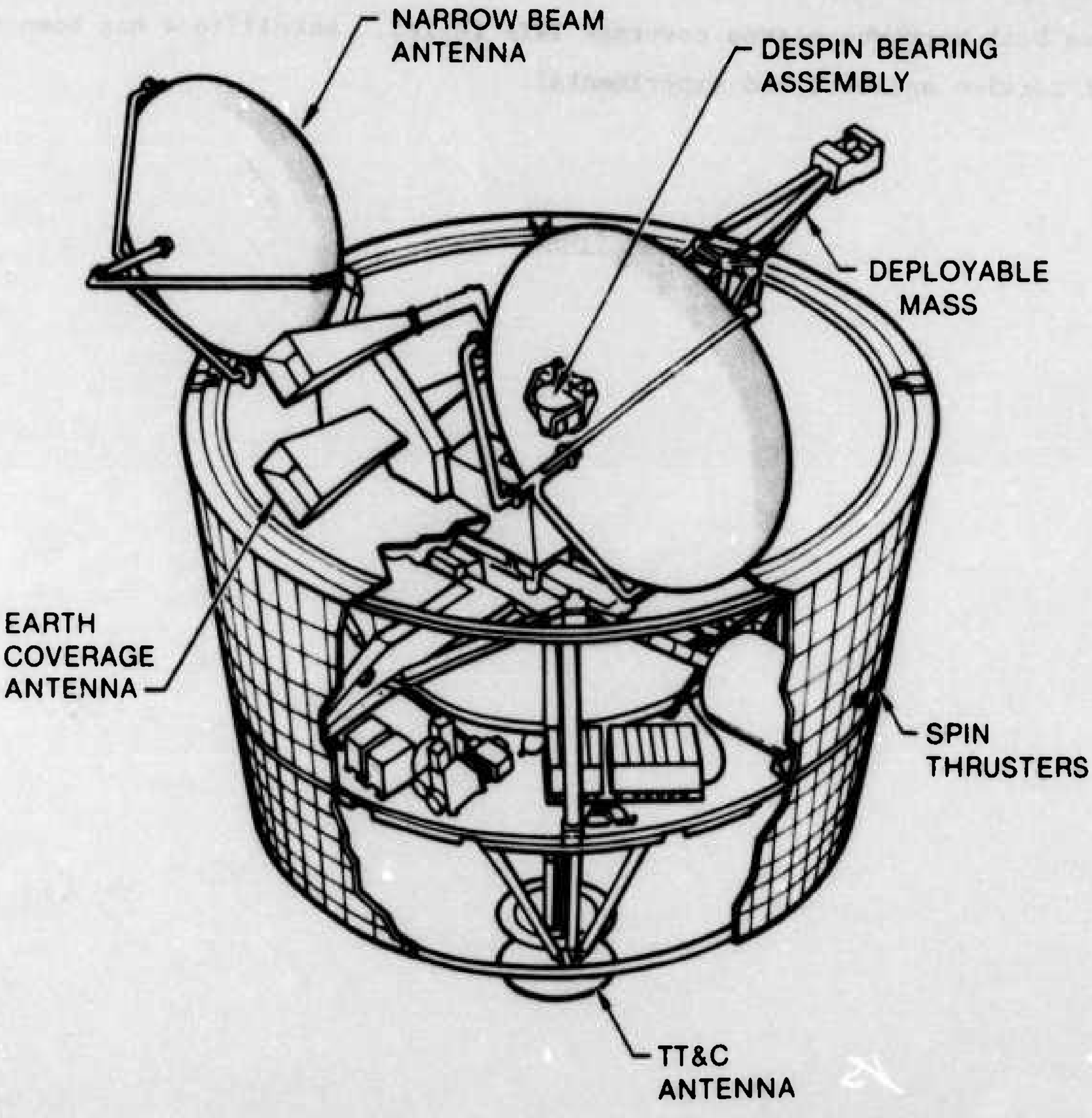


Figure 5-7. DSCS II Satellite

Table 5-4. DSCS II Details

Satellite	Cylinder, 9-ft diameter, 6 ft high, overall height 13 ft 1350 lb in orbit, beginning of life Solar cells and NiCd batteries, 520 W initially, 388 W minimum at 5 yr Spin-stabilized, 60 rpm, 0.2° antenna pointing accuracy
Configuration	4 channels with 50- to 185-MHz bandwidths, single conversion (see text)
Capacity	1300 two-way voice circuits or ~100 Mbps digital data
Transmitter	7250 to 7375, 7400 to 7450, 7490 to 7675, 7700 to 7750 MHz 2 independent transmitters, 1 for the 2 earth coverage channels, 1 for the 2 narrowbeam channels 20-W output per transmitter (40 W for satellites 13-16) ERP: Satellites 1 to 6: 28 dBW, earth coverage 43 dBW, one narrowbeam antenna 40 dBW, each of two narrowbeam antennas Satellites 7 to 12: 28 dBW, earth coverage 43 dBW, narrowbeam antenna 31 dBW, area coverage antenna 40/28 dBW, using both narrowbeam and area coverage Satellites 13 to 16: 31 dBW, earth coverage 46 dBW, narrowbeam antenna 34 dBW, area coverage antenna 40/33 dBW, using both narrowbeam and area coverage Earth coverage specified at $\geq$7.5° earth terminal elevation angle; narrowbeam and area coverage anywhere within beamwidth
Receiver	7900 to 7950, 7975 to 8100, 8125 to 8175, 8215 to 8400 MHz Tunnel diode preamplifiers and limiter/amplifiers 7-dB noise figure
Antenna	2 earth coverage horns (1 transmit and 1 receive), 16.8-dB gain at edge of earth 2 narrowbeam parabolas, 44-in. diameter, 2.5° beamwidth, 36.5-dB gain on axis, steerable $\pm$10° each axis; on satellites 7-16 one antenna has been defocused to a 6° beamwidth for area coverage

Table 5-4. DSCS II Details (Continued)

	All antennas mounted on a despun platform and circularly polarized
Design Life	5 yr (3 yr MMD)
Orbit	Synchronous equatorial, inclination <3^{o}
Orbital History	1-2: Launched together 2 Nov 1971; operated 20 and 8 months
	3-4: Launched together 13 Dec 1973; 3 operated 33 months; 4 is experimental, 66^{o}E longitude
	5-6: Launched together 20 May 1975; left in low orbit by launch vehicle failure, reentered 26 May 1975
	7-8: Launched together 12 May 1977; 7 taken out of service May 1979; 8 is a spare, 180^{o} longitude
	9-10: Launched together 25 Mar 1978; launch vehicle failure
	11-12: Launched together 13 Dec 1978; 11 is a spare, 130^{o}W longitude; 12 is operational, 60^{o}E longitude
	13-14: Launched together 21 Nov 1979; 13 is operational, 175^{o}E longitude; 14 is operational, 11^{o}W longitude
	15: To be launched with DSCS III-A2
	16: Launched 30 Oct 1982 with DSCS III-A1, a spare, 15^{o}W longitude
	Titan IIIC launch vehicle (1 to 14)
	Titan 34D/IUS launch vehicle (16)
	Titan 34D/Transtage (15)
Developed for	AF Space Division (formerly SAMSO)
Developed by	TRW Systems Group
Operated by	Defense Communications Agency; TT&C support by SCF[a]

[a]Satellite Control Facility (U.S. Air Force)

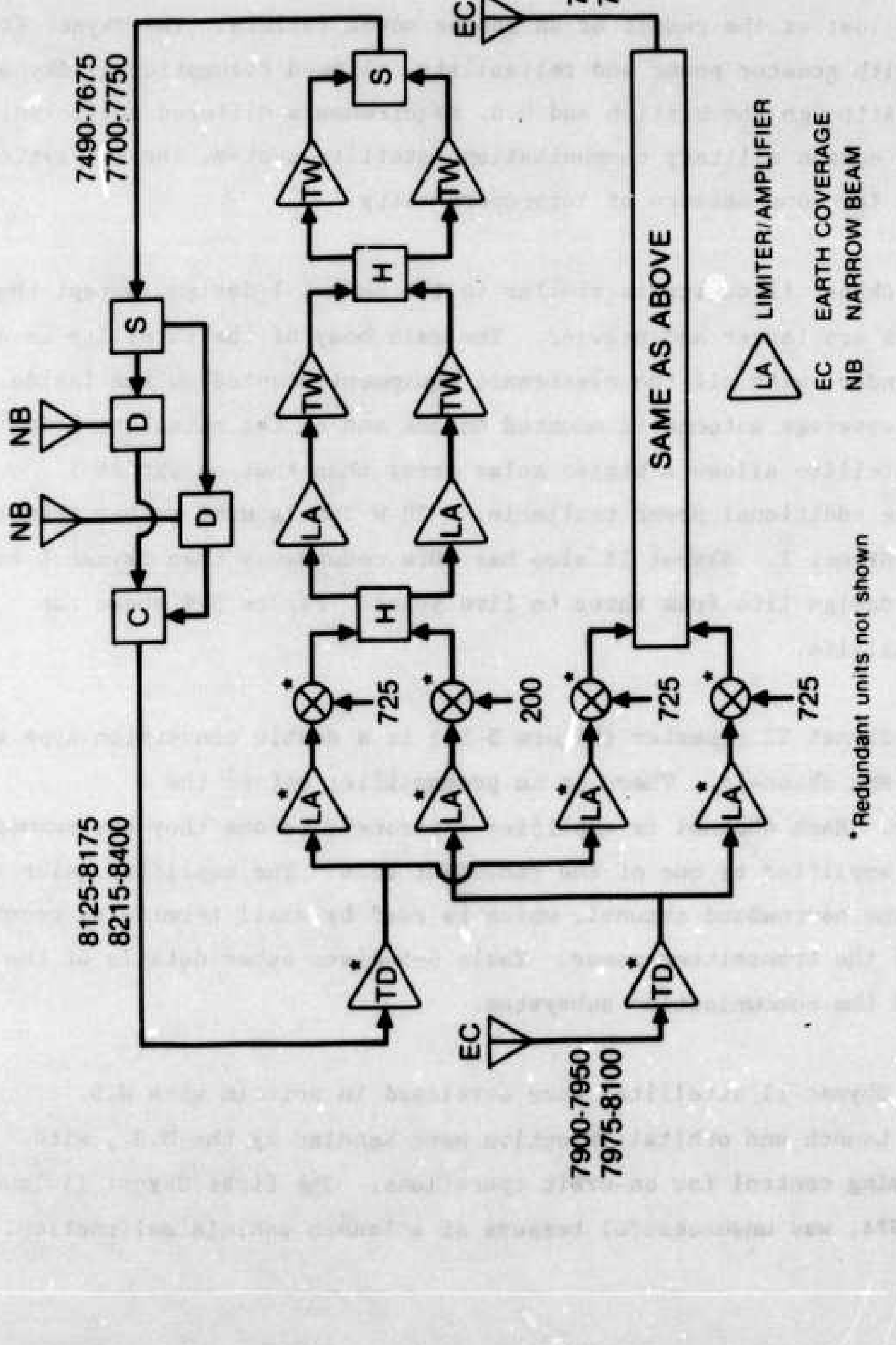


Figure 5-8. DSCS II Communication Subsystem

5.5 SKYNET II (Refs. 232, 239, 244-248)

Skynet is the name of the British military communication satellite system. The first generation satellites (Skynet I) were launched in 1969 and 1970. One of these satellites operated successfully for several years, but the other was lost as the result of an apogee motor failure. The Skynet II satellites, with greater power and reliability, allowed resumption of Skynet operations. Although the British and U.S. requirements differed sufficiently to preclude a common military communication satellite system, the two systems were designed for some measure of interoperability.

The Skynet II design is similar to the Skynet I design, except that the satellites are larger and heavier. The main body of the satellite is a spinning cylinder, with all the electronic equipment mounted on the inside. A despun earth coverage antenna is mounted on one end of the satellite body. The larger satellite allows a bigger solar array than that on Skynet I. Because of the additional power available, a 20-W TWT is used rather than the 3.5-W TWT on Skynet I. Skynet II also has more redundancy than Skynet I to increase the design life from three to five years. Figure 5-9 shows the Skynet II satellite.

The Skynet II repeater (Figure 5-10) is a double conversion type with 2-MHz and 20-MHz channels. There is no preamplifier before the downconverter. Each channel is amplified separately before they are summed, limited, and amplified by one of the redundant TWTs. The amplifier gains are set so that the narrowband channel, which is used by small terminals, receives 80 percent of the transmitter power. Table 5-5 gives other details of the satellite and the communication subsystem.

The Skynet II satellites were developed in Britain with U.S. assistance. Launch and orbital injection were handled by the U.S., with Britain assuming control for on-orbit operations. The first Skynet II launch, in January 1974, was unsuccessful because of a launch vehicle malfunction.

The remaining satellite was launched in November 1974 and was still in use at the end of 1978. However, the command system failed early in 1977 and therefore, the satellite longitude cannot be controlled.

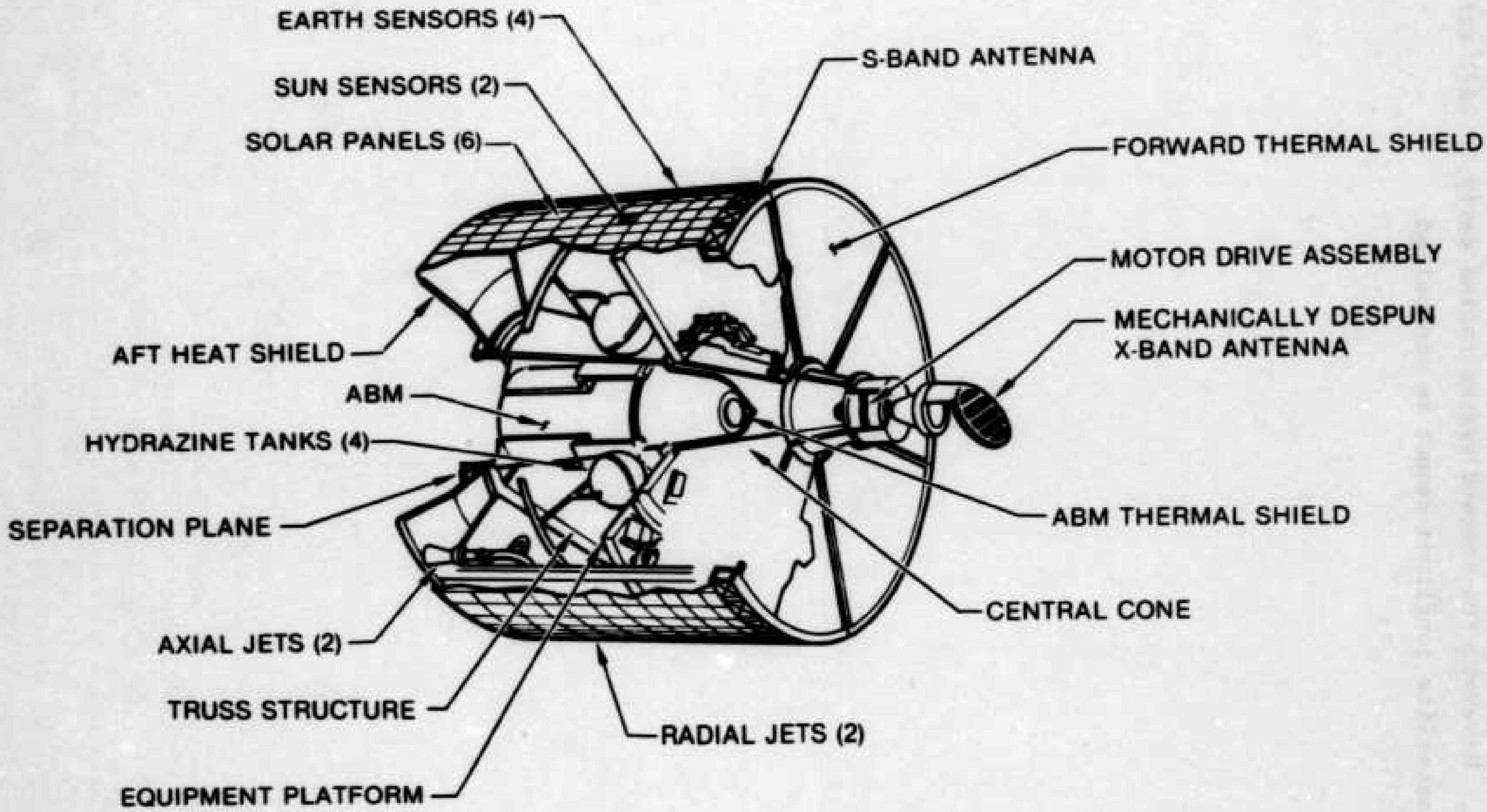


Figure 5-9. Skynet II Satellite

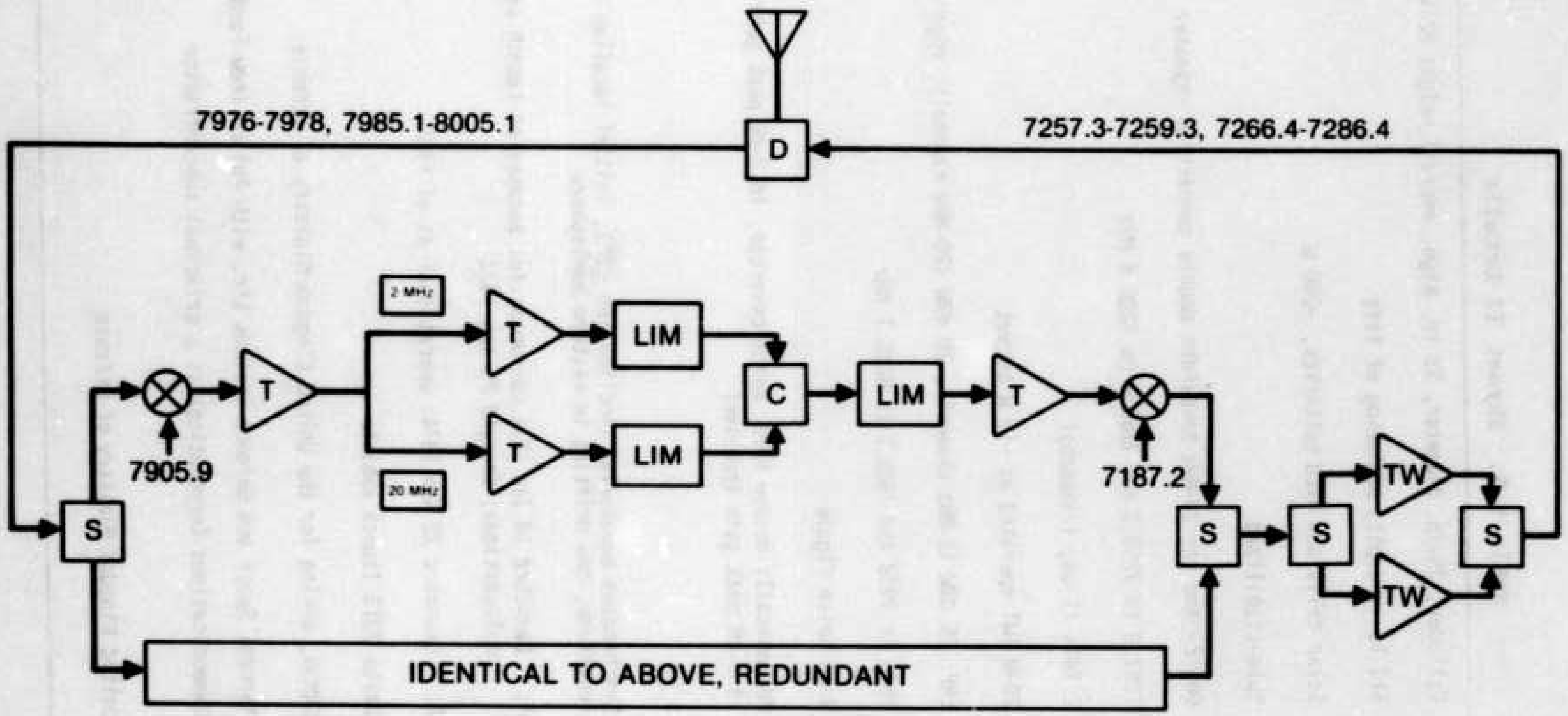


Figure 5-10. Skynet II Communication Subsystem

Table 5-5. Skynet II Details

Satellite	Cylinder, 75-in. diameter, 53 in. high, overall height 82 in. 517 lb in orbit, beginning of life Solar cells and NiCd batteries, ~200 W Spin-stabilized
Configuration	One 2- and one 20-MHz bandwidth double conversion repeater
Transmitter	7257.3 to 7259.3 and 7266.4 to 7286.4 MHz 2 TWTs (1 on, 1 standby) 20-W TWT operated at ~18 W output ERP: 26 dBW (2-MHz channel), 20 dBW (20-MHz channel), edge of earth
Receiver	7976 to 7978 and 7985.1 to 8005.1 MHz 9-dB noise figure
Antenna	Mechanically despun horn, earth coverage, 18.7-dB peak gain (transmit), 19.9-dB peak gain (receive)
Design Life	5 yr
Orbit	Synchronous equatorial (inclination $\leq 3^{o}$), initial location about 49^{o}E longitude, now drifting in eastern hemisphere
Orbital History	A: Launched 18 Jan 1974 (unsuccessful because of launch vehicle malfunction); decayed 25 Jan 1974 B: Launched 22 Nov 1974; operational as of 1981 Delta 2313 launch vehicle
Developed for	SAMSO, acting for the United Kingdom Ministry of Defense
Developed by	Marconi Space and Defence Systems Ltd. with Philco (now Ford Aerospace and Communications Corporation) as a principal subcontractor
Operated by	United Kingdom Ministry of Defense

5.6 GAPFILLER/GAPSAT (Refs. 144, 249-255)

Tacsat and LES-6 were the first tactical communication satellites to be used by the U.S. Navy. However, they were both experimental satellites put into operational status, and thus afforded only a limited operational capability. The Navy began developing the FLTSATCOM system in 1971 to provide a full operational capability with global deployment. Tacsat failed in 1972 and LES-6 was deteriorating. Since the first FLTSATCOM launch was not expected until 1977, the Navy faced a "gap" in satellite availability. Therefore, in 1973 the Navy contracted for an interim satellite service to fill this gap. This service is called Gapsat or Gapfiller.

Each Gapfiller satellite has three UHF channels for the Navy, one wideband (500 kHz) and two narrowband (25 kHz). The wideband channel was chosen to have the same bandwidth and frequency as the LES-6 channel, and the narrowband channel bandwidth was set equal to the FLTSATCOM channel bandwidth. The minimal Navy commitment was to lease, for at least two years, the wideband channels of two satellites. The first satellite was launched in February 1976 and began operation the next month in the Atlantic area. Concurrently, LES-6 was turned off. The second satellite was launched in June 1976 and began operations in the Pacific area the same month. The wideband channels were divided into subchannels with FDMA operation with a capacity of five 2400-bps, one 1200-bps, and thirteen 75-bps links. One narrowband channel was also put into use by the Navy and the second was subleased to the Army. In October 1976 the third Gapfiller, which is primarily a spare for the other two, was launched to provide service in the Indian Ocean. At the same time, the leases on all three satellites were extended into 1979. Additional extensions continued Gapfiller service into 1983, on some channels. The British Navy began leasing some capacity on the Atlantic satellite early in 1981.

The Gapfiller service does not require the full capability of the satellites being used and, therefore, the additional channels are being used for communications between shore stations and commercial ships. This is called the Marisat system. These satellites, which are called either Gapfiller/Gapsat or Marisat satellites depending on the context, are described in detail in Section 7.3.

5.7 NATO III (Refs. 144, 238-239, 256-261)

The NATO communication satellite program began in 1967. The first phase was the experimental use of the IDCSP satellites with two ground terminals. The second phase began in 1970 with the launch of the first NATO satellite. A second satellite was launched in 1971. These satellites were very similar to the Skynet II satellites. The NATO III satellites are larger and have significantly greater capabilities than the earlier NATO satellites.

NATO III is a spin-stabilized satellite with a cylindrical body and a despun antenna platform on one end. All equipment is mounted within the body, and a three-channel rotary joint connects the communications subsystem with the antennas. The satellite, shown in Figure 5-11, has a design life of seven years. Satellite details are given in Table 5-6.

NATO III has three communication channels with 17-, 50-, and 85-MHz bandwidths, all of which can be used simultaneously. All channels are received through a horn antenna with a pattern covering the North Atlantic region including the east coast of North America, all of Western Europe, and the Mediterranean. This is called widebeam coverage. After a common preamplifier, the three channels are separated and each is amplified in a TDA. All these units are redundant. The 50-MHz channel is transmitted through the widebeam transmit path, while the other two channels are combined in the narrowbeam path. There are four tunnel-diode-driver, traveling-wave-tube-amplifier (TWTA) chains available. Each path has a choice among three chains, although both paths cannot use a TWTA simultaneously. The widebeam transmit antenna is a horn with the same coverage as the receiving antenna. A larger horn provides narrowbeam coverage of Western Europe only. The three antennas (one receive, two transmit) are each connected to separate channels in the rotary joint. Figure 5-12 is a block diagram of the communication subsystem. Figure 5-13 shows the widebeam and narrowbeam coverages.

A qualification model and two flight model satellites were constructed. The first was launched in April 1976 and has been in operation since orbital testing was completed. NATO IIIB was launched in January 1977 as an orbiting spare. It was loaned to the U.S. to fill the East Pacific operating location of the DSCS system until at least four DSCS II satellites were available. This goal was realized as a result of the DSCS II launch in December 1978. DSCS traffic was removed from NATO IIIB in January 1979, and it was returned to its station over the Atlantic Ocean. The qualification model has been reworked into the third flight model and was launched in November 1978. In 1980 a follow-on contract was issued for a fourth satellite, which was launched in November 1984. The contract included an option for a fifth satellite, but the option was not exercised. At the end of 1982, NATO IIIB was turned on to assume the active role in the system. NATO IIIA, though having some performance degradations, is still used for tests. NATO IIIC and NATO IIID are in-orbit spares.

The NATO III satellites are part of the NATO satellite communications system. This system has a main control center and an alternate control center. About two dozen ground terminals (Figure 5-13), most with 42-ft antennas, communicate through the satellites. All transmissions are digital, and share the satellite via FDMA. The satellite communication system is a part of the NATO Integrated Communications System, which also has various terrestrial communications links and switching and control nodes.

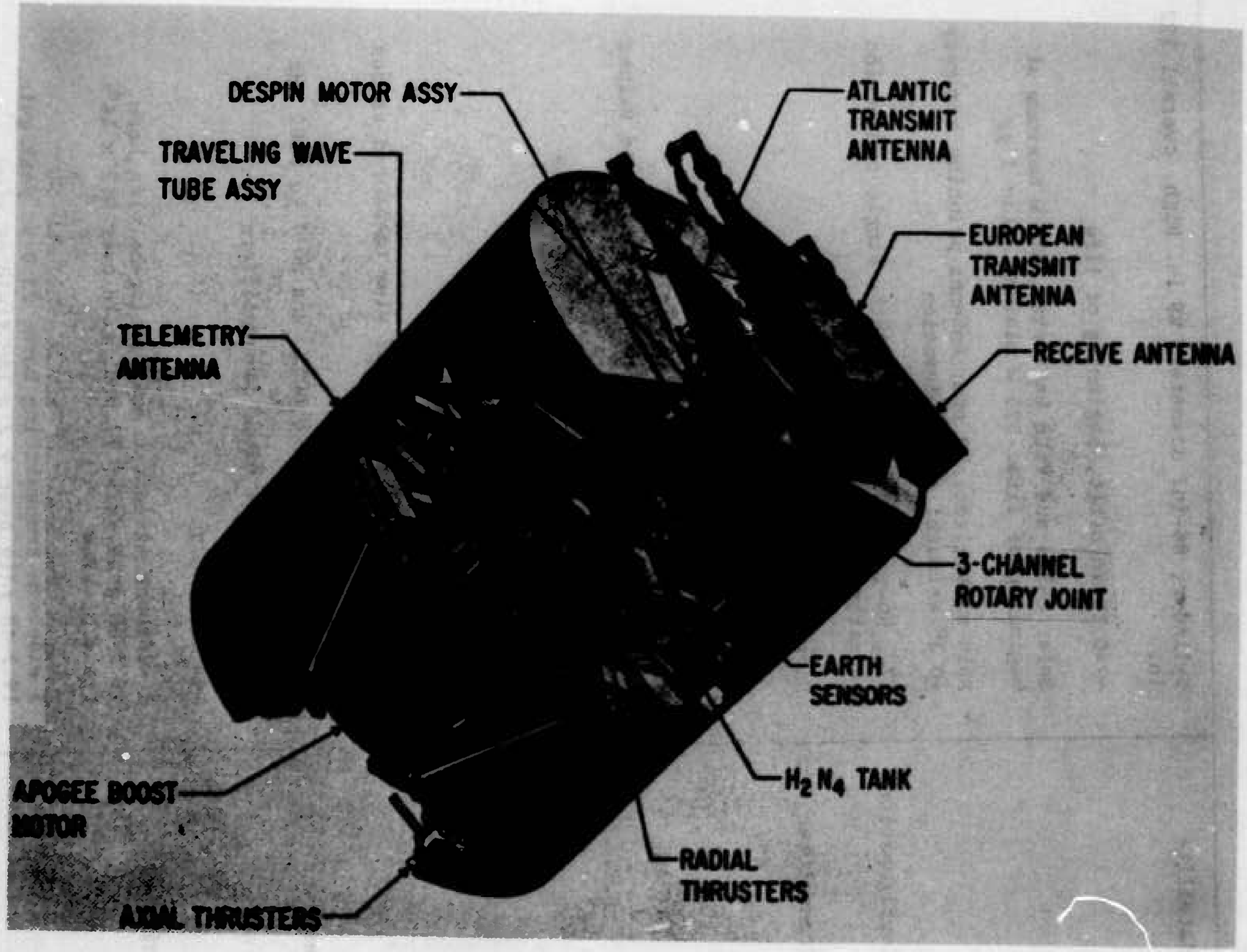


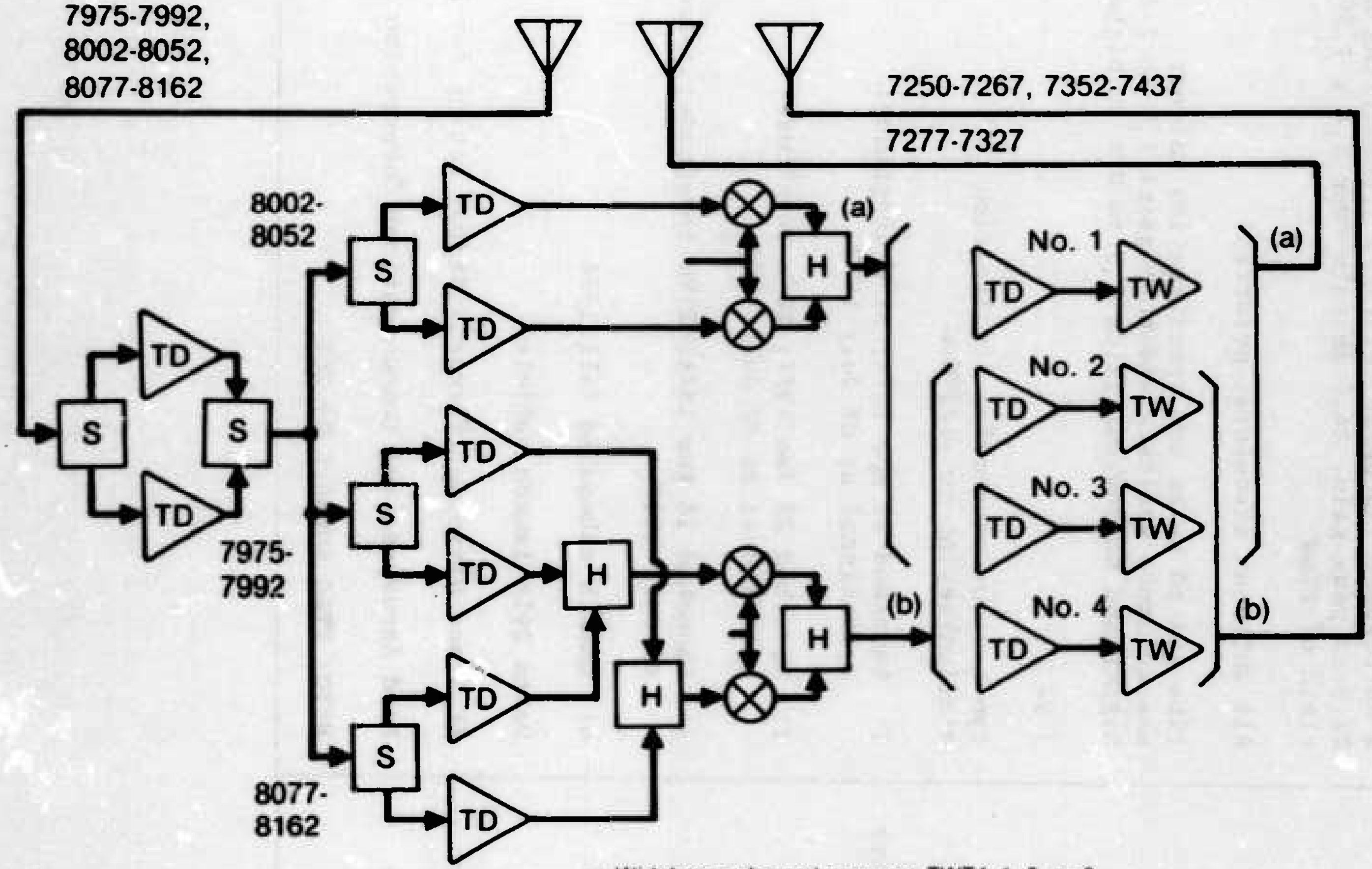
Figure 5-11. WATO III Satellite

Table 5-6. NATO III Details

Satellite	Cylinder, 86-in. diameter, 88 in. high, overall 122 in. ~740 lb in orbit, beginning of life Solar cells and NiCd batteries, 538 W maximum at beginning of life, 375 W minimum after 7 yr Spin-stabilized, 90 rpm; antenna pointing accuracy $\pm 0.3^{\circ}$ azimuth, $\pm 0.4^{\circ}$ elevation
Configuration	17-, 50-, and 85-MHz bandwidth, single conversion repeaters
Transmitter	Narrowbeam (European coverage): 7250 to 7267 and 7352 to 7437 MHz 20-W output power 35-dBW ERP over field of view (measured values have been >36.5 dBW) Widebeam (Atlantic coverage): 7277 to 7327 MHz 20-W output power 29-dBW ERP over field of view (measured values have been >31 dBW)
Receiver	7975 to 7992, 8002 to 8052, and 8077 to 8162 MHz Redundant tunnel diode preamplifiers -14 dB/$^{\circ}$K G/T
Antenna	1 widebeam (Atlantic coverage) receiving horn, 18.5-dB peak gain, 17.0-dB gain over 9.2 x 16° field of view 1 widebeam transmitting horn, 23.0-dB peak gain, 19.3-dB gain over 9.2 x 16° field of view

Table 5-6. NATO III Details (Continued)

	1 narrowbeam (European coverage) transmitting horn, 27.5-dB peak gain, 24.5-dB gain over 5.4 x 7.7° field of view All antennas circularly polarized (The listed gains are specification values; measurements indicate widebeam gains 1.3 to 2 dB higher and narrowbeam gains 0.5 to 0.8 dB higher)
Design Life	7 yr
Orbit	Synchronous equatorial (inclination $\leq 3^{\circ}$), stationkeeping to $\pm 1/2^{\circ}$E-W
Orbital History	1: Launched 22 Apr 1976; 31°W longitude; operational as of July 1983 2: Launched 27 Jan 1977; 18°W longitude; operational as of July 1983 3: Launched 18 Nov 1978; 21°W longitude; spare as of July 1983 4: Launch scheduled fall 1984 Delta 2914 launch vehicle
Developed for	AF Space Division (formerly SAMSO) acting for NATO
Developed by	Ford Aerospace and Communications Corporation
Operated by	NATO; TT&C support by SCF



(a) Widebeam channel may use TWTA 1, 2, or 3
(b) Narrowbeam channel may use TWTA 2, 3, or 4
(both channels do not simultaneously use the same TWTA)

Figure 5-12. NATO III Communication Subsystem

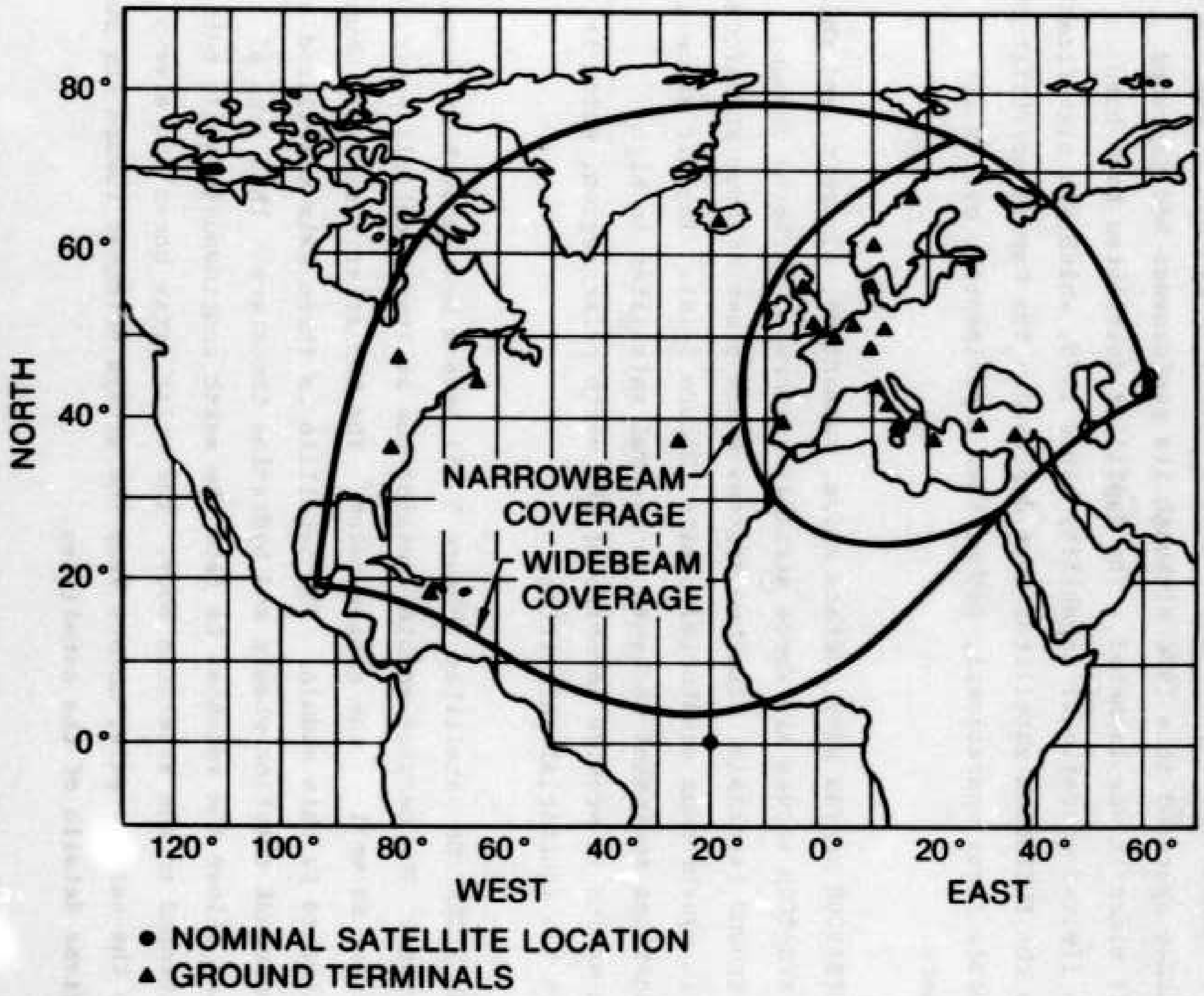


Figure 5-13. NATO Terminal Locations

5.8 FLTSATCOM AND AFSATCOM (Refs. 144, 238-239, 249, 255, 262-276)

Tacsat and LES-5 and -6 were experimental satellites that demonstrated UHF (225- to 400-MHz band) links with mobile terminals. These satellites were used for numerous tests, and Tacsat and LES-6 provided a limited operational capacity for DoD. Tacsat ceased to operate at the end of 1972, and LES-6 operated into 1976 although its performance had degraded considerably since it was launched. The Gapfiller satellites have been providing a limited operational capability since 1976, which was significantly improved as the FLTSATCOM satellites were deployed. The Gapfiller/FLTSATCOM system is DoD's first operational, rather than experimental, system for tactical users.

FLTSATCOM serves Navy surface ships, submarines, aircraft, and shore stations. AFSATCOM serves Air Force strategic aircraft, airborne command posts, and ground terminals. The two systems share a set of four FLTSATCOM satellites in synchronous equatorial orbits (Figure 5-14). The Air Force also has communications equipment packages on several satellites in high inclination orbits to provide coverage of the north polar region, which is not visible from the equatorial satellites.

The FLTSATCOM satellites (Figure 5-15) have a hexagonal body composed of two sections. The service module contains the attitude control, power, and TT&C subsystems as well as the apogee motor. The two solar arrays are mounted on booms attached to this module. The satellite is three-axis-stabilized by means of redundant reaction wheels and hydrazine thrusters. This type of stabilization allows the antennas to face the earth continuously while being directly attached to the satellite body. The solar array booms are always parallel to the earth's axis; motors keep the arrays oriented toward the sun. Table 5-7 gives details of the satellites.

The other section of the satellite contains the communication subsystem. The antennas are mounted on the earth-viewing side of this module. The largest antenna is for UHF transmissions and is a 16-ft diameter paraboloid with a solid center section. The outer part of the surface is a

mesh that is attached to 12 ribs. The mesh is deployed, along with the solar arrays, after the satellite is injected into synchronous orbit. The separate UHF receiving antenna is a single helix about one ft in diameter and 11 ft long, deployed to the side of the large paraboloid. The third antenna is a horn that is used for reception of the X-Band (super high frequency [SHF]) fleet broadcast uplink and transmission of an X-band beacon.

The satellite has four types of communication channels (Figure 5-16). The Navy will use one fleet broadcast channel and nine 25-kHz bandwidth fleet relay channels. The Air Force will use 12 narrowband (5-kHz each) channels and one wideband (500-kHz) channel. All links, except the fleet broadcast uplink, are in the 240- to 400-MHz band with the downlinks at the lower part of the band. The fleet broadcast uplink frequency is about 8 GHz. Either processing or nonprocessing receivers may be used with the fleet broadcast and some Air Force narrowband uplinks. Use of the processing receivers provides some antijam capability. The satellite has 12 power amplifiers, one for each of the Navy channels, one for the Air Force narrowband channels, and one for the Air Force wideband channel. A UHF command channel is provided on FLTSATCOM for operational control of the Air Force narrowband package and limited redundancy switching of the fleet broadcast channel.

The fleet broadcast channel has an information rate of 1200 bps composed of 15 teletype and one synchronization channel at 75 bps each. The initial use of each fleet relay channel is a single 1200- or 2400-bps link. To make better use of the channel capacity, the Navy is changing to TDMA transmissions with preassignment, and followed by automated demand assignment. Tests of TDMA with demand assignment were conducted in 1978. The TDMA format uses burst rates between 9.6 and 32 kbps. Each narrowband Air Force channel will be used for a single 75-bps link. The wideband channel will be used for multiple FDMA links at 75 bps or a single higher rate link.

AFSATCOM does not have its own satellites for the polar coverage orbits. Rather, UHF communications packages are placed on other DoD satellites. These packages have capabilities similar to those of the 12 narrowband Air Force channels on the FLTSATCOM satellites. In addition, AFSATCOM will use a single channel transponder with antijam improvements on DSCS III satellites.

Satellites 7 and 8 will have an EHF communications package with a 44-GHz uplink and 20-GHz downlink. This package is being developed by Lincoln Laboratory and will provide for testing and early operational use of the EHF communications, which will be a major part of MILSTAR.

The EHF package is housed in a third hexagonal module added to the satellite (Figure 5-15). The additional weight is accomodated by an improved launch vehicle and a new apogee motor. New solar cells, with higher efficiency than those used on satellites 1 to 5, will provide the added power with no increase in solar array size.

The EHF package has both earth coverage and spot beam antennas. It demodulates up to 32 received signals, processes them, and reformats and modulates them for downlink transmission. The uplinks are FDMA; they are combined into a single TDM data stream for the downlink. Both links are frequency hopped. Additional information is given in Table 5-7. Figure 5-17 is a block diagram of the EHF package.

The FLTSATCOM program began with five satellites. Congress reduced the program to three but later the other two were restored. The first satellite was launched in February 1978, and the fifth was launched in August 1981. The first four satellites formed a constellation with global coverage. Each has operated properly since it was put in orbit. The fifth satellite is a spare. It was damaged during the latter part of ascent, and has limited capability.

In 1982 an additional three satellites were added to the program. These will be used, with the Leasats, to provide service to the growing user community through the middle and latter part of the 1980s. They will be replaced by the MILSTAR satellites.

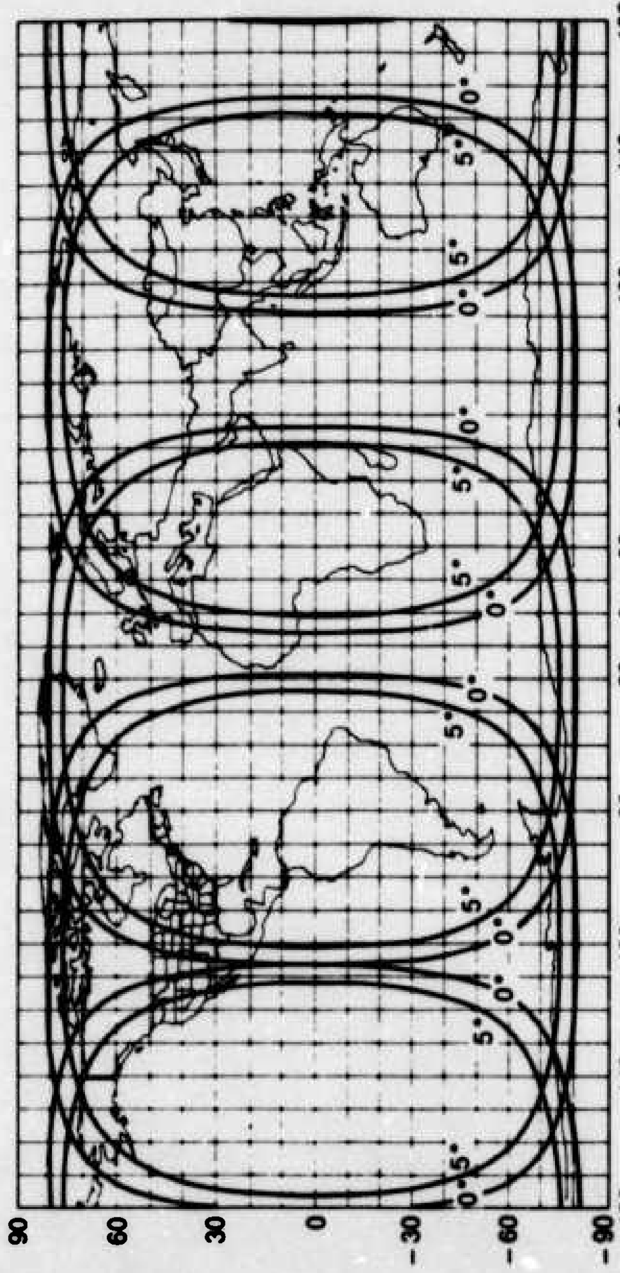


Figure 5-14. FLTSATCOM Communication Coverage

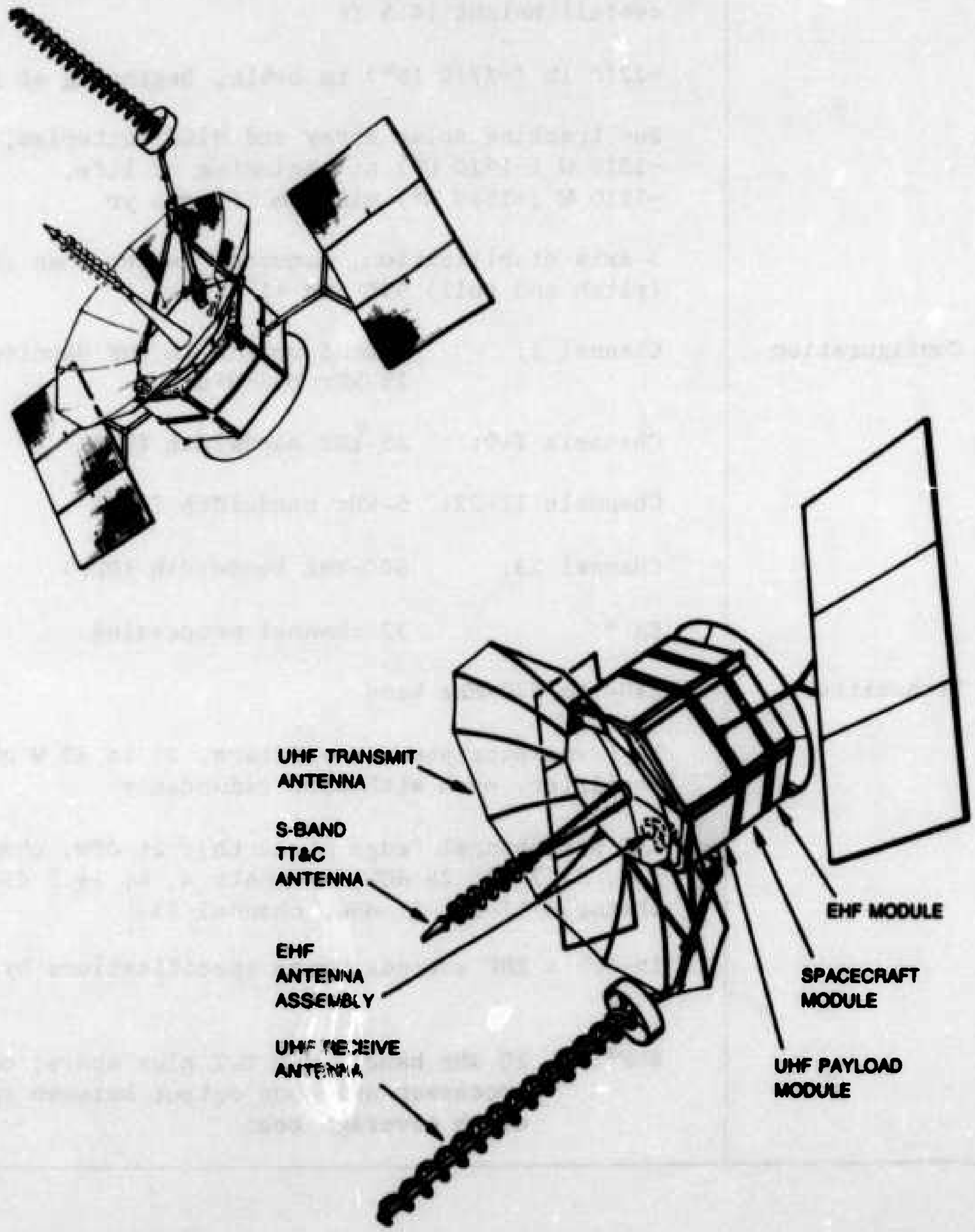


Figure 5-15. FLTSATCOM Satellite

Table 5-7. FLTSATCOM Details

Satellite	Hexagon, 8 ft across, 4 ft (5 ft[a]) high, with 2 deployed solar arrays (each approximately 9 x 13 ft) and a 16-ft deployed antenna, overall span ~43 ft, overall height 14.5 ft ~2270 lb (~2770 lb[a]) in orbit, beginning of life Sun tracking solar array and NiCd batteries, ~1570 W (~1920 W[a]) at beginning of life, ~1210 W (~1560 W[a]) minimum after 5 yr 3-axis stabilization, accuracy better than $\pm 0.2^{\circ}$ (pitch and roll) 99% and $\pm 1^{\circ}$ (yaw) 3
Configuration	Channel 1: X-band uplink to UHF downlink, 25-kHz bandwidth Channels 2-9: 25-kHz bandwidth (UHF) Channels 11-22: 5-kHz bandwidth (UHF) Channel 23: 500-kHz bandwidth (UHF) EHF[a]: 32 channel processing
Transmitter	240- to 270-MHz band 12 transistor power amplifiers, 25 to 43 W output per amplifier, each with some redundancy ERP per channel (edge of earth): 26 dBW, channels 1-3, 5, 7-10; 28 dBW, channels 4, 6; 16.5 dBW, channels 11-22; 27 dBW, channel 23 In-orbit ERP exceeds these specifications by about 2 dB EHF[a]: 20-GHz band; 20-W TWT plus spare; onboard processor switches output between spot and earth coverage beam

Table 5-7. FLTSATCOM Details (Continued)

Receiver	290 to 320 MHz, 8 GHz, and 44 GHz[a]
Antenna	16-ft deployable UHF parabola, earth coverage, circularly polarized Deployable UHF helix, 1-ft diameter, 11 ft long, earth coverage, circularly polarized X-band horn, earth coverage, circularly polarized EHF[a]: steerable 5° spot beam with separate 20- and 44-GHz feeds; two earth coverage horns (1 each for 20 and 44 GHz)
Design Life	5 yr (3.1 yr MMD predicted before first launch; 7 yr MMD expected from experience through 1982)
Orbit	Synchronous equatorial (inclination <3°); stationkeeping to ±1°E-W
Orbital History	1: Launched 9 Feb 1978, in use, 99°W longitude 2: Launched 4 May 1979, in use, 72°E longitude 3: Launched 17 Jan 1980, in use, 23°W longitude 4: Launched 30 Oct 1980, in use, 172°E longitude 5: Launched 6 Aug 1981, limited capability, spare, 44°W longitude 6: Launch scheduled Jul 1985 7: Launch scheduled Jul 1986 8: Launch scheduled Aug 1987 Atlas-Centaur launch vehicle
Developed for	AF Space Division (formerly SAMSO)
Developed by	TRW Systems Group
Operated by	Naval Telecommunications Command; TT&C support by SCF

[a]Satellites 7 and 8.

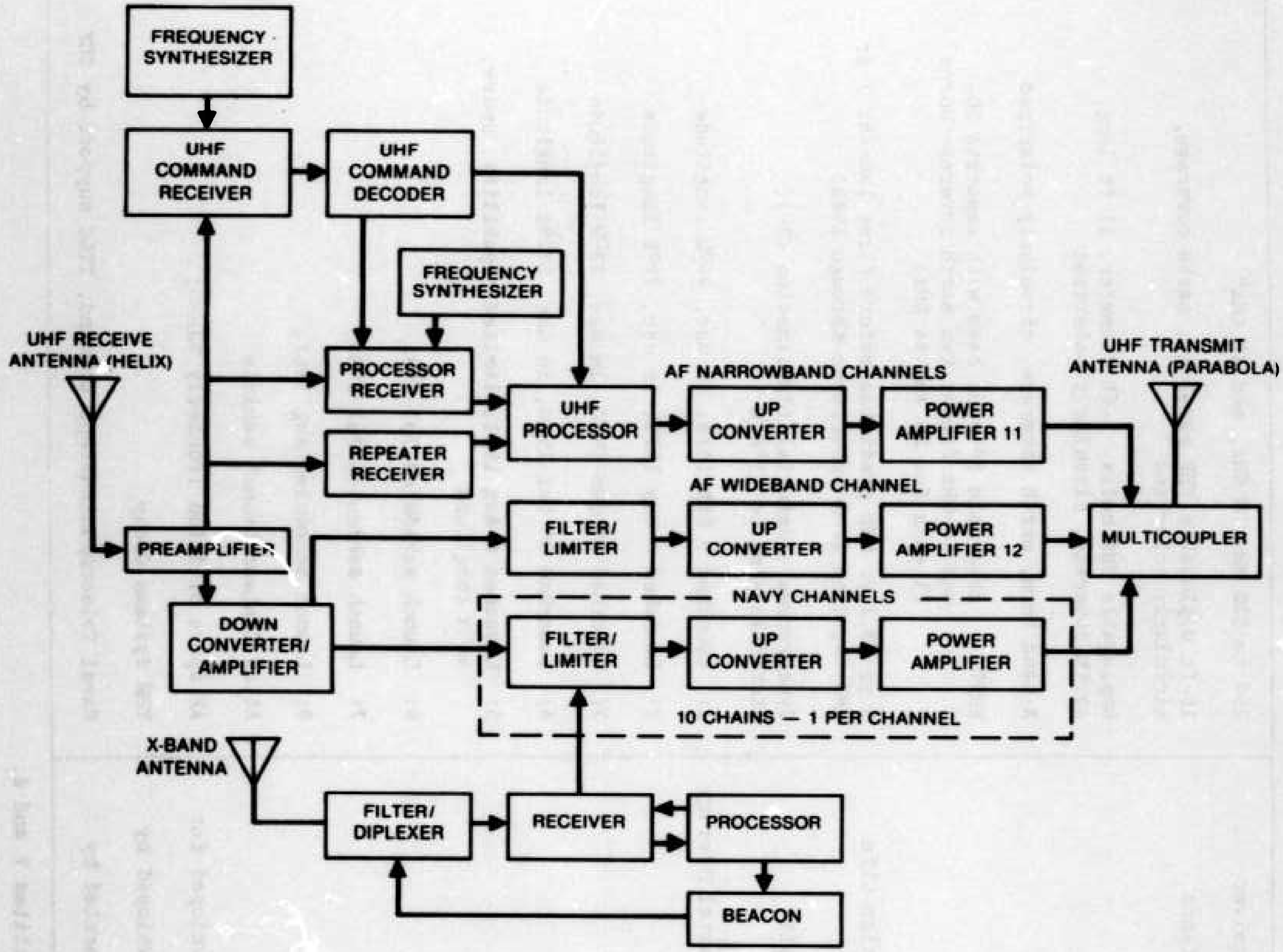


Figure 5-16. FLTSATCOM Communication Subsystem

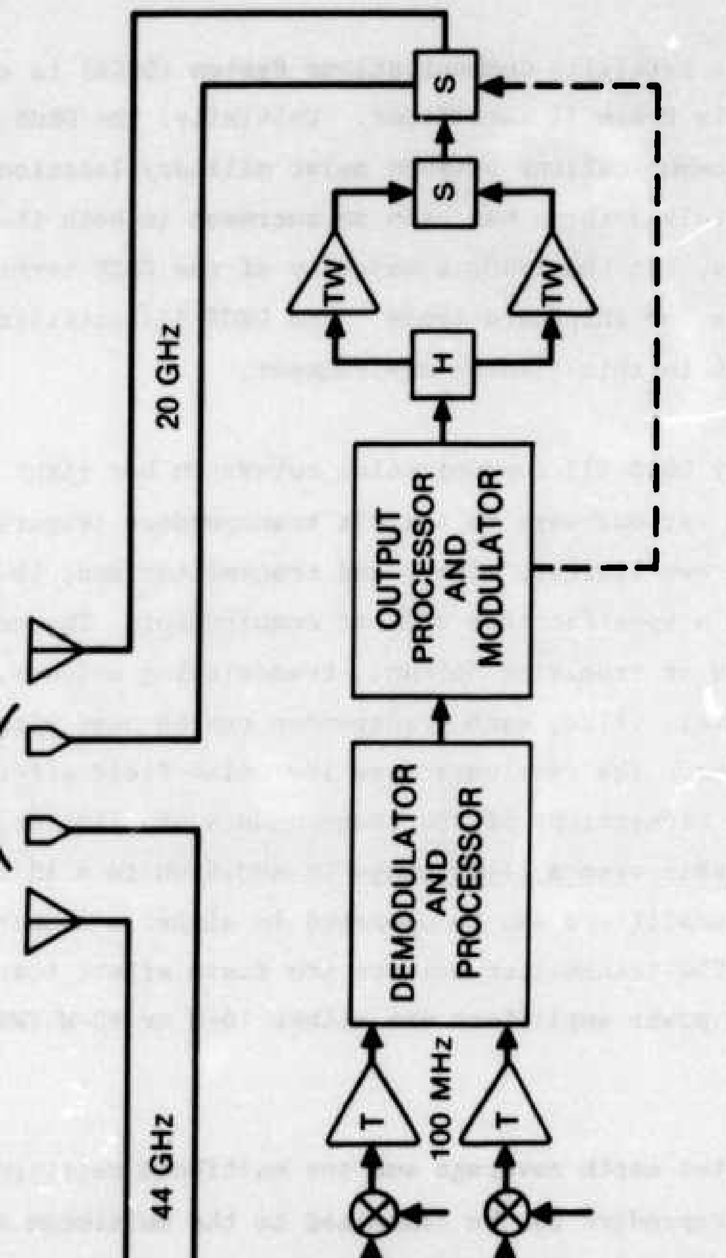


Figure 5-17. FLTSATCOM EHF Communication Subsystem

5.9 DSCS-III (Refs. 237, 277-283)

The Defense Satellite Communications System (DSCS) is currently using one Phase III and six Phase II satellites. Initially, the DSCS was planned for long distance communications between major military locations. However, as the system has evolved there has been an increase in both the number and variety of terminals. In the 1980s a majority of the DSCS terminals may be small, transportable, or shipboard types. The DSCS III satellites are being developed to operate in this diverse environment.

The primary DSCS III communication subsystem has eight antennas that can be connected in various ways to the six transponders (Figure 5-18). Each transponder has its own limiter, mixer, and transmitter and, thus, can be configured to serve a specific type of user requirement. The configuration includes the choices of receiving antenna, transmitting antenna, and transponder gain level. Also, each transponder can be used with either FDMA or TDMA transmissions. The receivers have low noise field effect transistor preamplifiers. The midsections of the transponders are limiter amplifiers with a gain commandable over a 24-dB range in addition to a 15 dB commandable attenuator. These amplifiers can be operated in either a linear, quasilinear, or limiting mode. The transmitter drivers are field effect transistor amplifiers, and the power amplifiers are either 10-W or 40-W TWTs or solid state amplifiers.

There are two earth coverage and one multibeam receiving antennas. Four of the six transponders can be connected to the multibeam antenna (MBA). This antenna can form any beam of arbitrary size, shape, and location by means of a beam-forming network that controls the relative amplitudes and phases of each of the 61 individual beams. This antenna can also form nulls in selected directions in order to counter jammers. Two transmitters are always connected to earth coverage antennas, but the other four may all be connected to the 19-beam transmit MBAs. These antennas have the same capabilities as the receive MBA (except nulling) although their resolution is lower. Three of the

channels can also be switched to a gimballed dish antenna (GDA) that generates a single beam with high ERP.

The secondary communication subsystem on DSCS III is the AFSATCOM single channel transponder (SCT). The SCT has its own UHF transmitting and receiving antennas, but can be connected to the X-band earth coverage or MBA receiving antennas. The SCT demodulates the received uplink and remodulates it for transmission, and can also store messages for repeated transmission. The uplink has some antijamming protection. Beginning on satellite 4, the SCT will have an X-band downlink capability via the channel 1 TWT and multibeam antenna.

The DSCS III satellite (Figure 5-19) is three-axis-stabilized. All antennas except the GDA are mounted on the earth viewing face of the body and do not require deployment. The sun tracking solar arrays are deployed in orbit from the north and south faces of the satellite body. All support subsystems, except the solar arrays, are contained within the body. DSCS III has no apogee motor since it will be launched by either a Titan IIIC, or a Titan 34D with a transtage, or Shuttle vehicle with an inertial upper stage, all of which can place a satellite directly into synchronous equatorial orbit. The TT&C subsystem has an S-band section for use with the SCF, which is common to nearly all DoD satellites, plus an X-band section for use with the communications terminals. This affords redundant command paths into the satellite and allows the communications users direct control of the antennas and transponders. Table 5-8 gives details of the satellite and communications subsystem.

DSCS III design studies and breadboards of certain components, especially the MBAs, were done in 1976. Final development began in 1977 on a qualification model and two flight models, the first of which was launched in October 1982 with a DSCS II satellite, and is operational. The second will also be launched paired with a DSCS II. The third satellite is the refurbished qualification model. These three satellites are known as Block A. Eleven Block B satellites are on order. They have some solid state

amplifiers replacing TWTAs, a new X-band downlink capability for the AFSATCOM transponder via channel 1 of the main communications subsystem, and improved security equipment. Beginning with satellites III-B4 and III-B5, all will be dual launched on the Shuttle. The launches will establish and maintain an orbital constellation of four active and two spare satellites.

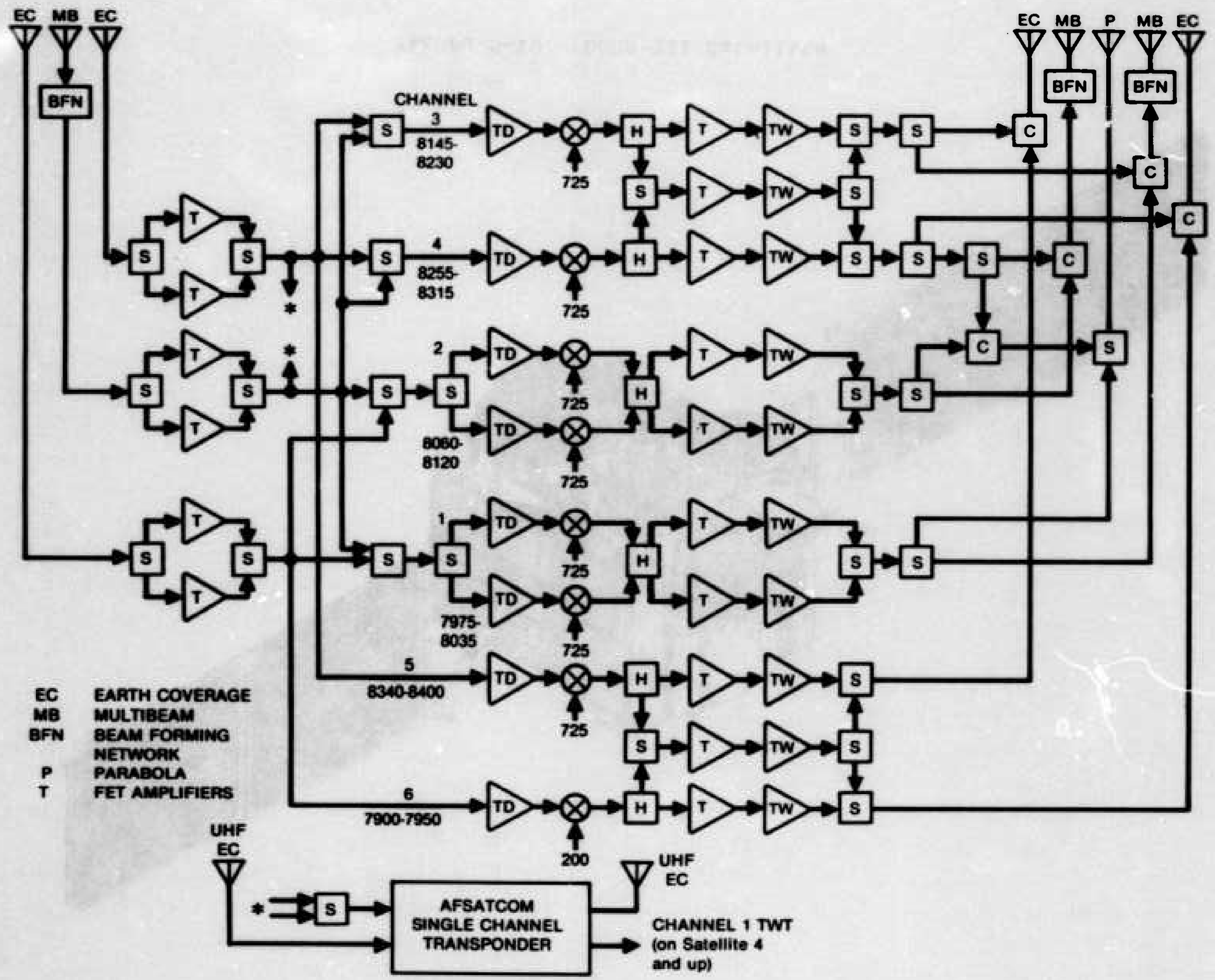


Figure 5-18. DSCS III Communication Subsystem

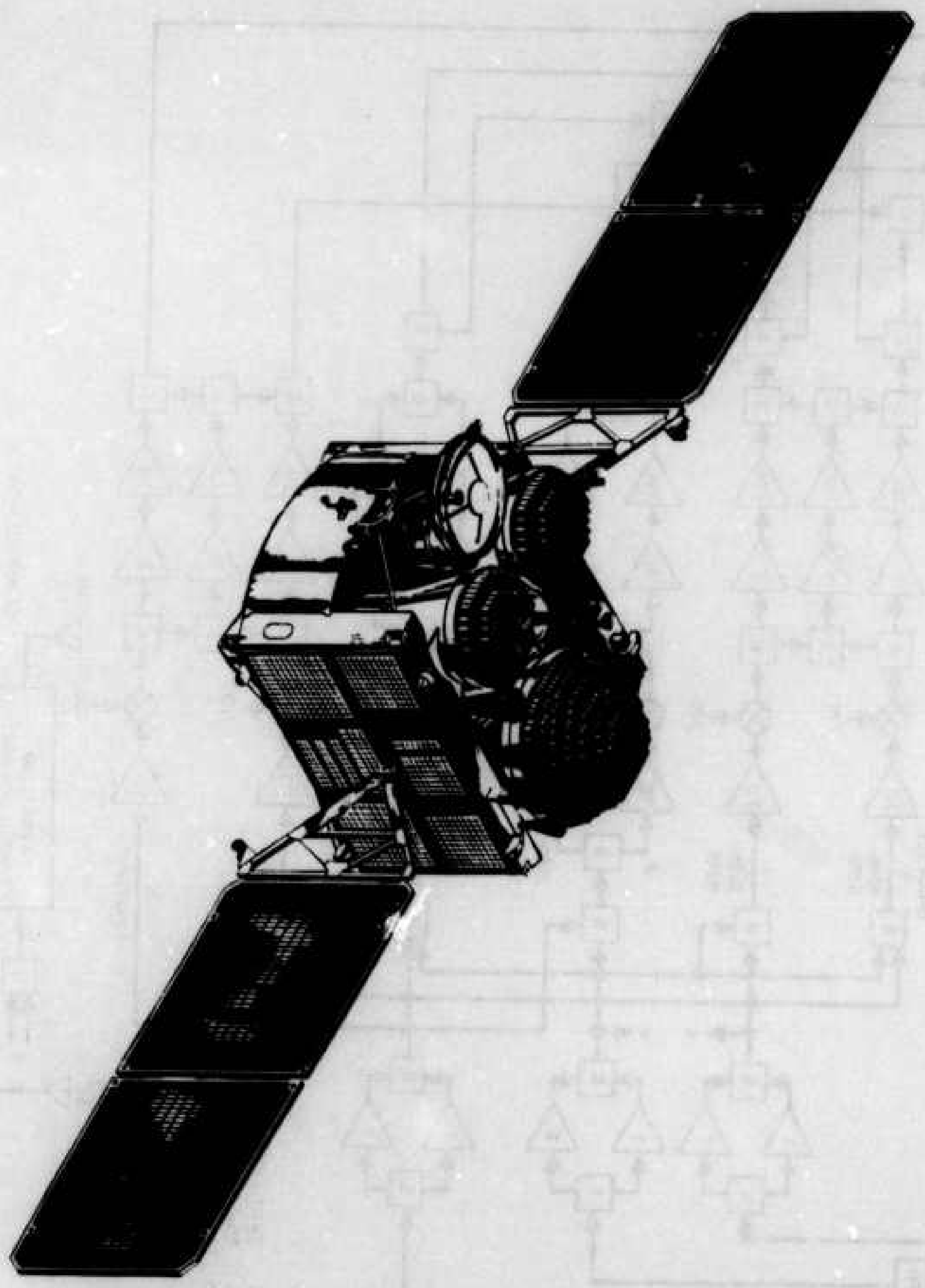


Figure 5-19. DSCS III Satellite

Table 5-8. DSCS III Details

Satellite	Rectangular, 6 x 6 x 7 ft, overall span of deployed solar arrays 38 ft
	2475 lb in orbit, beginning of life (2580 lb for satellite 4 and up)
	Sun tracking solar arrays and NiCd batteries, >1200 W beginning of life, 930 W after 10 yr
	3-axis stabilization, 0.08° accuracy in pitch and roll, 0.8° in yaw, 0.2° antenna pointing accuracy
Configuration	Six channels: 85-MHz bandwidth (channel 3), 50-MHz bandwidth (channel 6), 60-MHz bandwidth (channels 1, 2, 4, 5)
Transmitter	7250 to 7310, 7335 to 7395, 7420 to 7505, 7530 to 7590, 7615 to 7675, 7700 to 7750 MHz
	Channels 1 and 2: 40-W TWT and spare for each; ERP/channel: 40 dBW (MBA, narrow coverage); 29 dBW (MBA, earth coverage); or 44 dBW (GDA)
	Channels 3 and 4: 10-W TWT[a] for each and a shared spare; ERP/channel: 34 dBW (MBA narrow coverage); 23 dBW (MBA, earth coverage); 25 dBW (horn); or (channel 4 only) 37.5 dBW (GDA)
	Channels 5 and 6: 10-W TWT[a] for each and a shared spare; ERP/channel: 25 dBW (horn)
	SCT: UHF 70W, 21.3 dBW minimum ERP
	SHF commandable 0 to 100% of channel 1 TWT power (B4 and up), ERP depends on MBA configuration
	ERPs defined at edge of coverage
Receiver	7975 to 8035, 8060 to 8120, 8145 to 8230, 8255 to 8315, 8340 to 8400, 7900 to 7950 MHz
	FET preamplifiers
	Channels 1 to 6: G/T -1 $dB/^{\circ}K$ (MBA, narrow coverage); -16 $dB/^{\circ}K$ (MBA, earth coverage), or -14 $dB/^{\circ}K$ (horn), both at edge of coverage
	SCT (UHF): G/T -24.5 $dB/^{\circ}K$ minimum at edge of coverage
Antenna	Receive MBA: 45-in. aperture, 61 beams, narrow coverage performance defined for a 1° cone
	Transmit MBAs: 28-in. aperture, 19 beams, narrow coverage performance defined for a 1° cone
	Transmit GDA: parabola, 33-in. diameter, steerable, 3° beamwidth
	Horns: 2 transmit, 2 receive, earth coverage
	UHF: 1 transmit, 1 receive, crossed dipoles, 4 dB gain at edge of coverage
	All antennas circularly polarized

Table 5-8. DSCS III Details (Continued)

Design Life	10 yr (7 yr MMD)
Orbit	Synchronous equatorial, capable of $\pm 0.1^{\circ}$ stationkeeping N-S and E-W
Orbital History	1: Launched 30 Oct 1982 with DSCS II-16, operational, 135°W longitude
	2: To be launched DSCS II-15
	Titan 34D launch vehicle
	All subsequent satellites to be launched in pairs on the Shuttle
Developed for	AF Space Division (formerly SAMSO)
Developed by	General Electric
Operated by	Defense Communications Agency; TT&C support by SCF

[a]Gradual replacement with 10-W transistor amplifiers beginning on satellite 4.

5.10 LEASAT (Refs. 276, 284-292)

In the 1976 and 1977 Congressional reviews of the DoD budget for communication satellite systems, Congress directed DoD to increase its use of leased commercial facilities. This direction was specifically applied to the tactical satellite system that would follow FLTSATCOM. In the second half of 1977, the Defense Communications Agency (DCA), the Navy, and the Air Force developed technical, programmatic, and fiscal details for system alternatives that would satisfy DoD requirements within the Congressional guidelines. The result of this study is the Leasat program. Leasat will serve the Navy primarily, plus Air Force and ground forces mobile users. The FLTSATCOM terminal assets will be used with Leasat.

Leasat has four types of communication channels (Figure 5-20) with characteristics very similar to the FLTSATCOM channels. Channel 1 is for fleet broadcast use, and has an X-band uplink with spread spectrum antijamming protection. The spectrum spreading is removed by a satellite processor, and the data are transmitted on a UHF downlink. Channels 2 through 13 have UHF uplinks and downlinks with no satellite processing. Channel 2 has a 500-kHz bandwidth, channels 3 to 8 have 25-kHz bandwidths, and channels 9 to 13 have 5-kHz bandwidths. Channels 9 to 13 share a power amplifier; channels 1 through 8 each have a separate amplifier.

The Leasat satellite (Figure 5-21) has a dual-spin configuration with a cylindrical solar array about 14 ft in diameter and 9 ft high. The design is basically the same as the Syncom 4 design developed by Hughes Aircraft Co. in an effort to optimally match a satellite to the Space Shuttle launch system (Refs. 284-286). The central challenge in the Syncom 4 project was to find the combination of satellite geometry and upper stages that minimizes the mission cost for a given communications payload. This minimization is affected by three main facts. First, the payload bay diameter of the Shuttle is 15 ft, in contrast to the 8- and 10-ft fairing diameters of the launch vehicles used by most current communication satellites. Second, the Shuttle

launch cost is proportional to the fraction of the payload bay length used or the fraction of maximum payload weight capacity used, depending on which is greater. Third, the basic Shuttle orbit altitude is 150 nmi. An upper stage or stages are required to get the satellite into synchronous equatorial orbit.

Leasat is a spinning satellite with a despun communications and antenna platform. Allowing space for a cradle to hold the satellite in the Shuttle and to eject it properly, the satellite diameter was set at 14 ft. The length of the satellite body is set by the required size of the solar array. All required upper stage propulsion fits inside the satellite. In the bottom center of the satellite is a large solid propellant perigee motor that boosts the satellite into an elliptical transfer orbit after it is ejected from the Shuttle. In current satellites this position is occupied by the apogee motor, if one is used. In the Syncom 4/Leasat design the apogee boost function is provided by two liquid motors. These motors and the fuel tanks that feed them are mounted around the perigee motor. There is still sufficient volume within the satellite for the power supply electronics and batteries and the attitude control subsystem. The communication subsystem is mounted on the despun platform at the forward end of the satellite body. The antenna is also mounted on this platform and is folded down against it during launch, then deployed when the satellite is stabilized at synchronous altitude.

Leasat has five antennas on the despun platform. Two are X-band, earth coverage horns, one for receiving the channel 1 uplink and one for transmitting a beacon. An omnidirectional TT&C antenna is deployed in orbit. Two UHF helices are also deployed in orbit. Each provides earth coverage, one for transmission and one for reception. Other satellite details are given in Table 5-9.

The contract for Leasat development was awarded in September 1978, and is for five years of communication service to be provided at each of four orbital locations. The first launch was scheduled for 1982. However, delays in the Shuttle program delayed the launch dates and led to a two-year

suspension of work on the satellites. Work resumed early in 1983 with the first launch scheduled for spring 1984. The delayed introduction of Leasat has not caused any problems because the predecessor FLTSATCOM spacecraft have been operating much longer than expected. By the end of 1985 four Leasats should be in orbit to provide worldwide service.

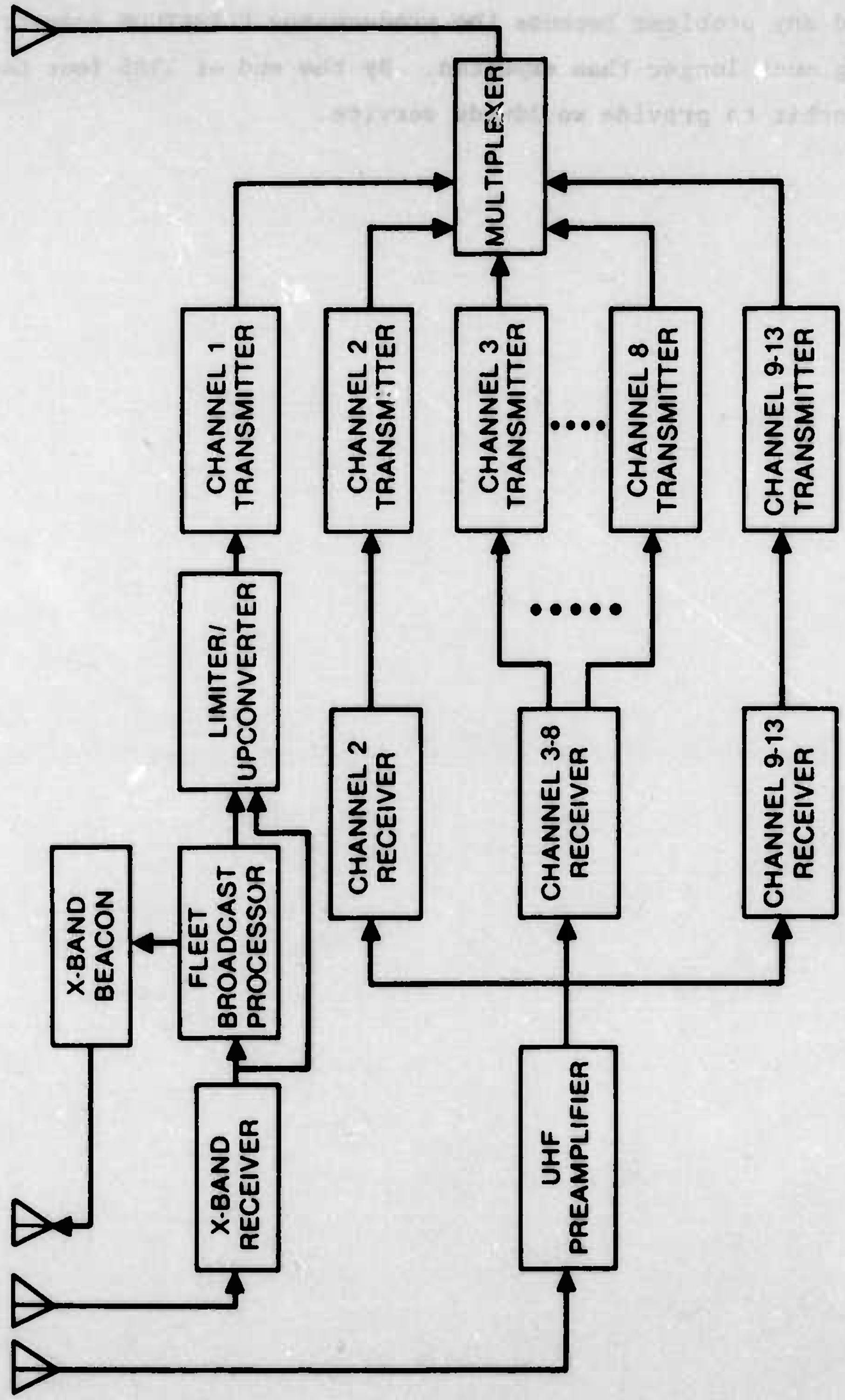


Figure 5-20. Leasat Communication Subsystem

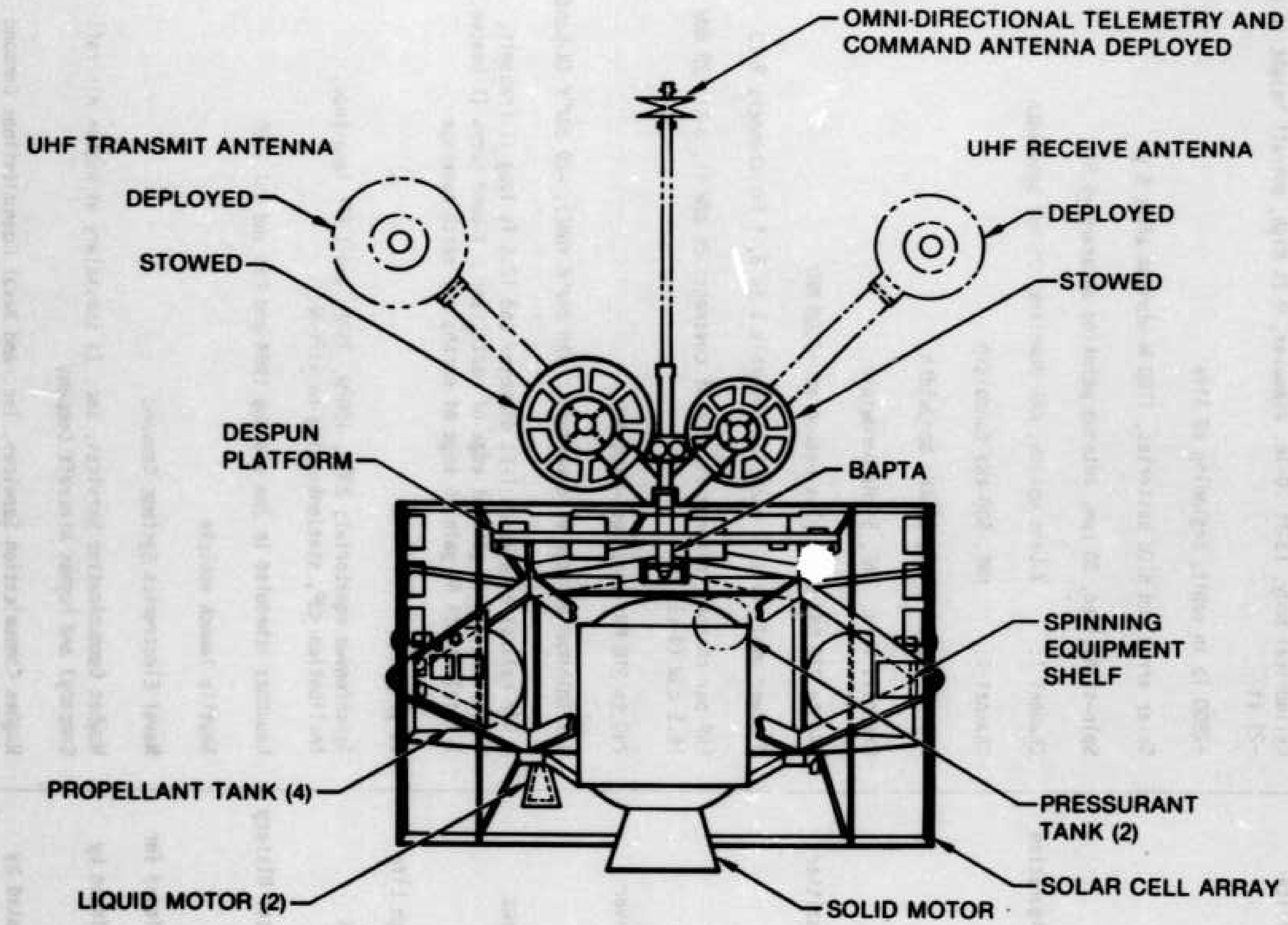


Figure 5-21. Leasat Satellite

Table 5-9. Leasat Details

Satellite	Cylindrical body, 13-ft 10-in. diameter, 9 ft high, overall height in orbit ~21 ft
	~2800 lb in orbit, beginning of life
	Solar array and NiCd batteries, 1180 W minimum after 5 yr
	Spin-stabilized, 30 rpm, antenna pointing accuracy $\pm 0.5^{\circ}$
Configuration	Channel 1: X-band uplink, UHF downlink, 25-kHz bandwidth
	Channel 2: UHF, 500-kHz bandwidth
	Channels 3-8: UHF, 25-kHz bandwidth
	Channels 9-13: UHF, 5-kHz bandwidth
Transmitter	244 to 270 MHz band, plus beacon at ~7300 MHz
	9 power amplifiers, 1 each for channels 1 to 8, 1 for channels 9-13
	ERP per channel, minimum at edge of coverage: 26 dBW (1, 3-8); 28 dBW (2); 16.5 dBW (9-13)
Receiver	290 to 318 MHz band and ~8000 MHz
	G/T (minimum at edge of coverage): -18 dB/°K (UHF), -20 dB/°K (X-band)
Antenna	2 UHF helixes each about 1-ft diameter and 12.6 ft long (1 transmit, 1 receive), 14 dB gain at edge of earth, and 2 X-band horns (1 beacon, 1 receive), 17 dB gain at edge of earth; all earth coverage
Design Life	10 yr
Orbit	Synchronous equatorial; 23°W, 100°W, 75°E, and 176°E longitude, inclination $\leq 3^{\circ}$, stationkeeping to $\pm 1^{\circ}$E-W
Orbital History	Launches scheduled in Jun and Aug 1984 and Feb and Jul 1985
	Shuttle launch vehicle
Developed for	Naval Electronics Systems Command
Developed by	Hughes Communication Services, Inc. (a subsidiary of Hughes Aircraft Company) and Hughes Aircraft Company
Operated by	Hughes Communication Services, Inc. and Naval Communications Command

5.11 SKYNET IV (Ref. 293)

Skynet is the British military satellite communications network. Skynet IIB, launched in November 1974, was the only satellite in use until the early 1980s. In 1981 the British began leasing some UHF channels on the Marisat satellites. These channels had been used by the U.S. under the Gapfiller program but were freed by the U.S. transition to FLTSATCOM.

The Skynet IV satellite development is intended to provide Britain with military communication satellites from the mid-1980s through the mid-1990s. In 1980 two British contractors, each teamed with a U.S. contractor, conducted studies of the satellite concept. Early in 1981 these two teams submitted proposals for satellite development. After reviewing the proposals, the British Ministry of Defense directed the two companies to submit a joint, "all-British" proposal. This was feasible since one company was strong in spacecraft and the other in communications payloads.

Development of Skynet IV began late in 1982. The satellite is three-axis-stabilized with deployed solar arrays, and is derived from the European ECS design. The communication subsystem has multiple channels in both the UHF-band used by FLTSATCOM and the X-band frequencies used by DSCS. Two satellites are being built, with a third probably to follow. They have a seven-year design life. The satellites will be launched on the Shuttle; the first is scheduled at the end of 1985.

5.12 MILSTAR (Refs. 294-296)

In the late 1970s and early 1980s the DoD operated three types of communication satellite assets: DSCS, FLTSATCOM supplemented by the Gapfillers, and AFSATCOM. THe FLTSATCOM satellites will gradually be replaced by the Leasats. Following Leasat, a major system improvement was planned for the 1990s. This improvement was called TacSatCom II. A major improvement for the AFSATCOM system was also planned. It was to start in the mid-1980s and was called the Strategic Satellite System (SSS).

Congressional opposition to these plans led to a consolidation of the two planned improvements into one new system, called MILSTAR. This system will provide service for mobile users in both strategic and tactical environments. MILSTAR will have space assets in both low and high inclination orbits to provide global coverage without single vulnerable nodes. Communications features include use of the EHF band (44-GHz uplinks, 20-GHz downlinks) to counter jamming threats, and intersatellite links to provide network flexibility. MILSTAR will also have UHF communications for compatibility with the approximately 1200 currently deployed UHF terminals.

The MILSTAR concept was defined in late 1981 and 1982. In the spring of 1983 a contractor was chosen for satellite development. The contract includes fabrication of one flight model satellite. The first launch is expected in the late 80s.

5.13 Defense Satellite Communications System (Refs. 236, 240, 282, 297-307)

The primary users of the DSCS satellites are the Worldwide Military Command and Control System, the ground mobile forces, Navy ships, wideband data relay, AUTOVON and AUTODIN, the White House Communications Agency, the Diplomatic Telecommunications System, and support to allied nations. In addition to the satellites, the DSCS includes a control segment and a variety of ground terminals.

At the beginning of the 1980s about 130 ground terminals of several types were in use. Other types were being developed to satisfy the increasing diversity of users in the DSCS. Airborne and shipborne terminals are the responsibility of the Air Force and Navy respectively; the Army is responsible for all other terminals. By the second half of the 1980s about 400 to 500 terminals will be in operation. The majority will be the truck and trailer mounted transportable types with 8-ft antennas, which are used by the ground mobile forces.

The terminal capabilities vary considerably (Table 5-10). Some smaller terminals have only a single link capability, whereas the FSC-78 terminals will be able to transmit as many as nine carriers and receive 12. The capacity of each link can vary from one to 96 voice circuits, or may be a combination of teletype and voice circuits or digital data at rates from several kilobits per second to greater than 10 Mbps. Some older terminals have only analog equipment, but newer terminals often have both analog and digital equipment. The system is planning to convert to all digital operations early in the 1980s. Currently, both FDMA and spread spectrum multiple access (SSMA) are used, with some terminals having both types of equipment. FDMA will eventually be changed to TDMA, and SSMA will be retained for protection against jamming.

The configuration of the DSCS network is not static. It is growing through the years, and within any year may vary as necessary to support the users' responses to world events. A typical configuration of the early 1980s,

indicating the connectivity between the fixed terminals, is shown in Figure 5-22. Each of the four satellites shown in the Figure has a primary and alternate network control station. These are located at major nodes such as Ft. Detrick, Maryland.

The DSCS control segment must allocate satellite capacity to best serve users requirements. New control segment computer algorithms are being developed and tested to provide an allocation process that can make use of the considerable flexibility of the DSCS III satellites. This flexibility includes the antenna patterns and connectivities and thus also involves variable ERP and G/T. The control segment developments include the ability to optimize the network configuration for both FDMA and SSMA operations, to respond to jammers, and to generate command sets to configure the satellite.

Table 5-10. DSCS Terminals[a]

Type	Use	Antenna Diameter (ft)	G/T (dB/°K)	ERP (dBW)	Transmission Power (kW)	Instantaneous Bandwidth (MHz)[b]
FSC-9[c]	Fixed, nodal	60	37	98	12.5	125
MSC-46[c]	Fixed or transportable	40	34	87/93	3/12.5	500/125
TSC-54[c]	Transportable	18	26.5	87	5	50
FSC-78[d]	Fixed, nodal	60	39	97	10	500
GSC-61[d]	Fixed or transportable	38	34	93	10	500
TSC-86 (LT-1)	Transportable	8	18	73	1	50
TSC-86 (LT-2)	Transportable	20	27	81	1	50
TSC-85	Tactical, ground-mobile[e]	8	18	70	0.5	50
TSC-93	Tactical, ground-mobile[e]	8	18	70	0.5	50
TSC-94	Tactical, ground-mobile[e]	8	18	70	0.5	50
TSC-100		8/20	18/27	70/81	1	50
WSC-6	Ship	4	12	65	3	500
SSC-6	Ship	6	15	80	12.5	125
ASC-24[f]	Airborne command post	2.75	7	74	12.5	125

[a]Terminals for Diplomatic Telecommunications Service and special applications are not listed.
[b]Transmission only; all terminals have 500-MHz instantaneous receiver bandwidth.
[c]These are modified Phase I terminals. All others are new developments for Phase II.
[d]The prototype FSC-78 was designated the MSC-60; the MSC-61 development became the GSC-61.
[e]No operation while in motion; setup time at destination is 20 min.
[f]The development phase terminal was designated ASC-18.

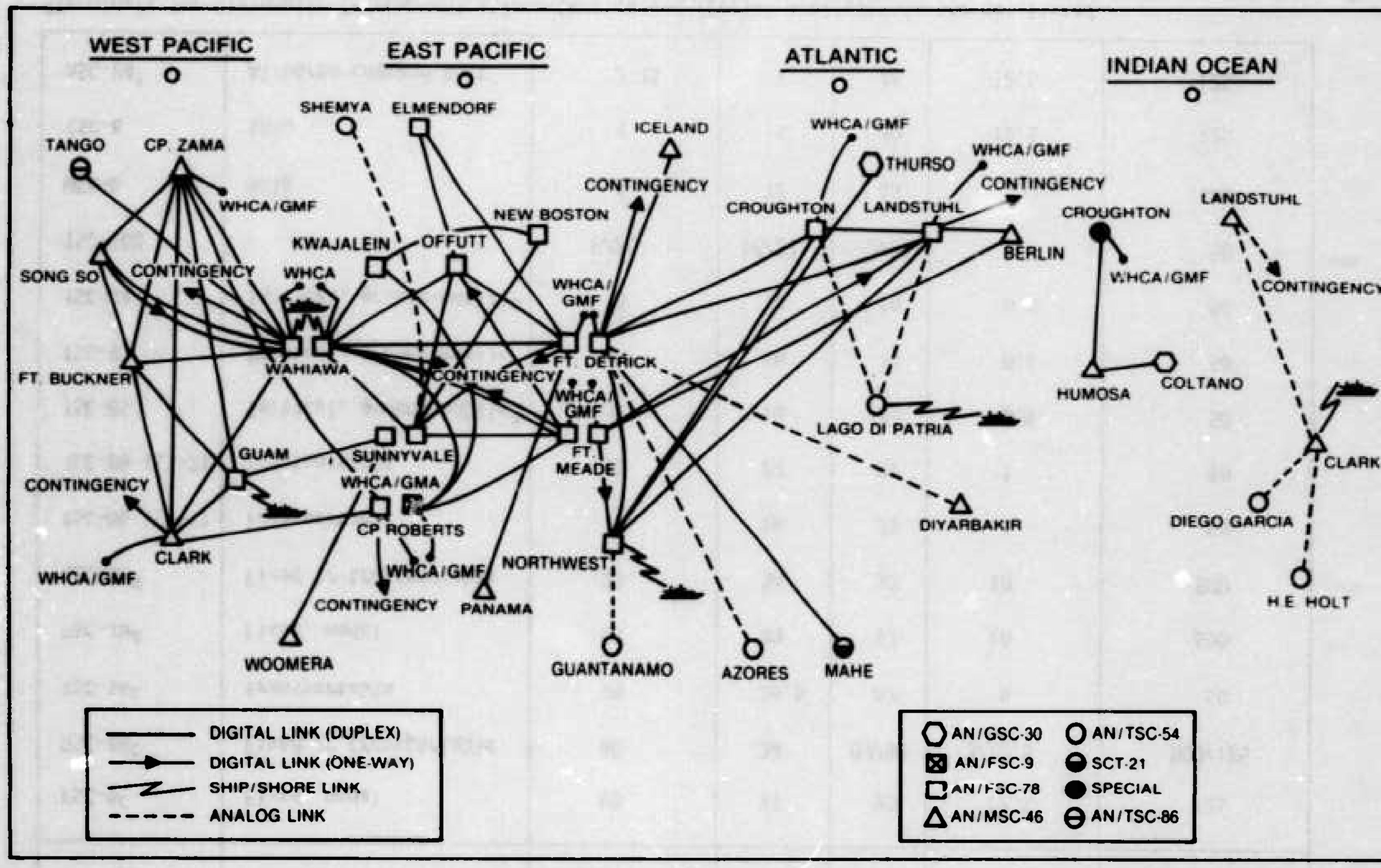


Figure 5-22. DSCS Network

6. U.S.S.R. SATELLITES

This section describes the communication satellites built and launched by the U.S.S.R. The most well known are the Molniya satellites, of which almost 100 have been launched since 1965. They use a high inclination elliptical orbit well suited to providing coverage of the Soviet land mass. In 1975 the U.S.S.R. began launching communication satellites into synchronous orbit. Several types exist, and others, though announced, have yet to be launched. The U.S.S.R. has also launched radio amateur communication satellites named RS or Radio. These are described in Section 8.1.2.

6.1 MOLNIYA (Refs. 308-317)

The U.S.S.R. has a very large land mass, much of which is undeveloped. This factor is a strong limitation on the development of terrestrial communication links. To overcome this limitation, the U.S.S.R. began to develop communication satellites early in the 1960s. This development led to production of the Molniya (Lightning) communication satellites which are used for both civilian and military communications. During the 1960s they were used primarily for communications internal to the Soviet Union, with a gradual expansion to international service in the 1970s.

Up to the middle of 1983, 96 Molniya satellites were launched (Table 6-1). According to announcements by the U.S.S.R., these satellites belong to three different series, each of which is described below. Molniya 1S, a satellite in synchronous equatorial orbit, is described in Section 6.2.

The Molniya satellites have been put into a 12-hour elliptical, inclined orbit. The apogee is over the northern hemisphere, so that a satellite is visible to ground stations in the U.S.S.R. for as much as nine hours during one orbit, and about 15 hours total per day. The inclination (62 to 65°) allows good visibility to all Soviet ground stations and affords coverage of the polar areas, which is not possible from a synchronous equatorial orbit. The high inclination orbit is easy to achieve from the high latitude Soviet launch sites (46 and 63°N), whereas significantly more energy is required for an equatorial orbit. The current Molniya 1 system consists of either four or eight active satellites in orbital planes whose right ascensions are 90 deg apart. The Molniya 2 and 3 satellites use the same four orbital planes.

The Molniya satellites relay signals between ground stations of the Orbita network. Stations that use the frequencies associated with the Molniya 2 and 3 satellites are designated Orbita 2. Orbita ground stations use antennas that are about 40 ft in diameter. Apparently some functions of the

Orbita network have been transferred to the Statsionar satellites in recent years.

6.1.1 Molniya 1

The Molniya 1 series of satellites has been in use since 1965. These were the first communication satellites developed by the U.S.S.R.; the only thing known about their development is that Cosmos 41 was flown as a test vehicle in 1964. This association was determined after the Molniya satellites began to be launched into the same orbit as Cosmos 41; the U.S.S.R. did not admit the relationship until five years after Cosmos 41 was launched.

The Molniya 1 satellites (Figure 6-1) use three-axis stabilization. Both solar panels and antennas are deployed after launch. The gimballed antennas are pointed at the earth while the whole satellite body is rotated to orient the solar array toward the sun.

The Molniya 1 communications subsystem can relay either a single television signal or duplex narrowband (e.g., telephone or telegraph) transmissions. About 40 W output power is used for transmission of a television signal; with narrowband operation, each of the two signals has an output power of about 14 W. The Molniya 1 design has probably been modified several times over the past 10 years. However, many details of the satellites have never been described, so it is impossible to determine how much the design has changed.

The first Molniya 1 was launched in April 1965. During its first day in orbit, television signals were exchanged between Moscow and Vladivostok. In 1966, the first increment of stations in the Orbita ground network became operational. These stations can receive television signals, and both receive and transmit voice, data, and facsimile signals. Moscow and Vladivostok are the two primary stations, and are the only ones to transmit television.

6.1.2 Molniya 2

The Molniya 2 satellites evolved from the Molniya 1 satellites, with the first launch in November 1971. The major change was the communication frequencies, which were in the 5.7-to 6.0-GHz band for reception and the 3.4-to 3.9-GHz band for transmission. Molniya 1 satellites use 0.8 to 1.0 GHz for both transmission and reception. Besides the frequency change, it seems that Molniya 2 had a greater communication capacity than Molniya 1. Some, or all, of the Molniya 2 satellites used horn antennas rather than the parabolic reflectors used on Molniya 1 satellites. In both cases the antenna pattern was approximately earth coverage (20° beamwidth) when the satellite was near apogee. The only obvious change in support subsystems was additional sections on the Molniya 2 solar array. The last Molniya 2 launch was in February 1977, so the system has apparently been phased out.

6.1.3 Molniya 3

The first Molniya 3 satellite was launched in November 1974. The basic characteristics of the Molniya 2 and Molniya 3 series seem to be the same, and no explanation has been given for the change in name. Apparently the Molniya 3 satellites have taken over the functions of the Molniya 2 series.

Table 6-1. Molniya Satellites

Satellite Series 1	2	3	Launch Date	Decay Date
1			23 Apr 1965	16 Aug 1979
2			13 Oct 1965	17 Mar 1967
3			25 Apr 1966	11 Jun 1973
4			20 Oct 1966	11 Sep 1968
5			24 May 1967	26 Nov 1971
6			3 Oct 1967	4 Mar 1969
7			22 Oct 1967	31 Dec 1969
8			21 Apr 1968	29 Jan 1974
9			6 Jul 1968	15 May 1971
10			5 Oct 1968	16 Jul 1976
11			11 Apr 1969	17 Apr 1974
12			22 Jul 1969	18 Jun 1971
13			19 Feb 1970	29 Sep 1975
14			26 Jun 1970	16 Feb 1976
15			29 Sep 1970	20 Mar 1976
16			27 Nov 1970	25 Nov 1975
17			25 Dec 1970	22 Dec 1975
18			28 Jul 1971	19 Jul 1977
	1		24 Nov 1971	10 May 1976
19			19 Dec 1971	13 Apr 1977
20			4 Apr 1972	30 Jan 1974
	2		19 May 1972	22 Mar 1977
	3		30 Sep 1972	12 Jan 1978
21			14 Oct 1972	1 Nov 1977
22			2 Dec 1972	11 Feb 1976
	4		12 Dec 1972	22 Jan 1975
23			3 Feb 1973	23 Oct 1977
	5		5 Apr 1973	6 Jan 1979
	6		11 Jul 1973	5 Aug 1978
24			30 Aug 1973	5 Dec 1979
	7		19 Oct 1973	8 Jul 1983
25			14 Nov 1973	26 May 1979
26			30 Nov 1973	
	8		25 Dec 1973	
27			20 Apr 1974	17 Nov 1983
	9		26 Apr 1974	
	10		23 Jul 1974	
28			24 Oct 1974	
		1	21 Nov 1974	
	11		21 Dec 1974	

Table 6-1. Molniya Satellites (Continued)

Satellite Series			Launch Date	Decay Date
1	2	3		
	12		6 Feb 1975	
		2	14 Apr 1975	
29			29 Apr 1975	
30			5 Jun 1975	
	13		8 Jul 1975	
31			2 Sep 1975	
	14		9 Sep 1975	
		3	14 Nov 1975	
	15		17 Dec 1975	
		4	27 Dec 1975	
32			22 Jan 1976	
33			11 Mar 1976	
34			19 Mar 1976	
		5	12 May 1976	
35			23 Jul 1976	
	16		2 Dec 1976	
		6	28 Dec 1976	
	17		11 Feb 1977	
36			24 Mar 1977	
		7	28 Apr 1977	
37			24 Jun 1977	
38			30 Aug 1977	
		8	28 Oct 1977	
		9	24 Jan 1978	
39			2 Mar 1978	
40			2 Jun 1978	
41			14 Jul 1978	
42			23 Aug 1978	
		10	13 Oct 1978	
		11	18 Jan 1979	
43			12 Apr 1979	
		12	5 Jun 1979	
44			31 Jul 1979	
45			21 Oct 1979	
46			11 Jan 1980	
47			21 Jun 1980	
		13	18 Jul 1980	
48			16 Nov 1980	
		14	9 Jan 1981	
49			30 Jan 1981	

Table 6-1. Molniya Satellites (Continued)

Satellite Series			Launch Date	Decay Date
1	2	3		
		15	24 Mar 1981	
		16	9 Jun 1981	
50			25 Jun 1981	
		17	17 Oct 1981	
51			17 Nov 1981	
52			23 Dec 1981	
53			26 Feb 1982	
		18	24 Mar 1982	
54			28 May 1982	
55			21 Jul 1982	
		19	27 Aug 1982	
		20	11 Mar 1983	
56			16 Mar 1983	
57			2 Apr 1983	
58			19 Jul 1983	
		21	31 Aug 1983	
59			23 Nov 1983	
		22	21 Dec 1983	
60			16 Mar 1984	

[a]Early Molniyas are sometimes designated 1B, 1C, etc., rather than 1-2, 1-3, etc.
[b]Cosmos 41, launched in August 1974, was a Molniya prototype.
[c]A discussion of the orbital decay of Molniya satellites may be found in Ref. 314.
[d]Molniya 1S is discussed in Section 6.2.

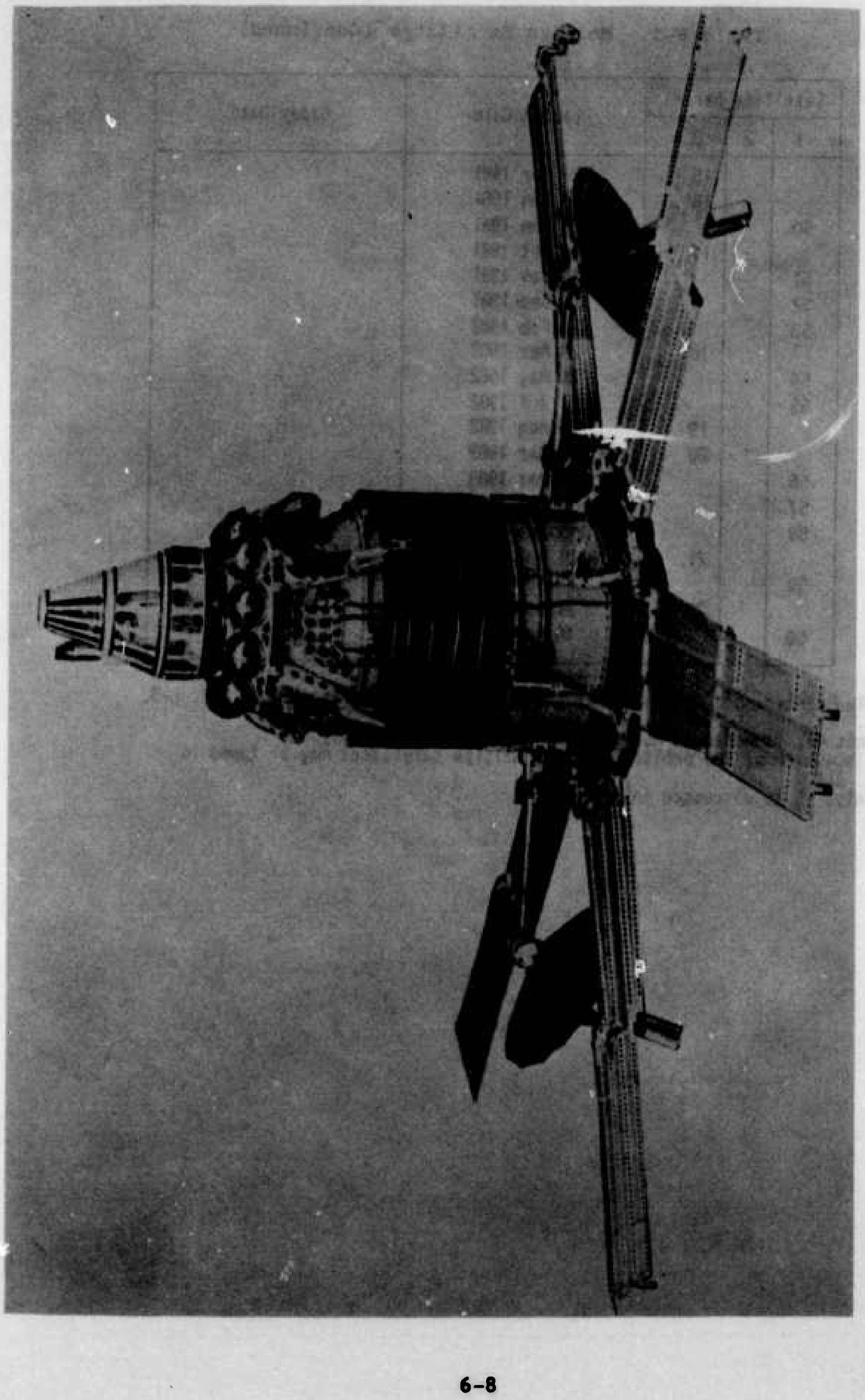


Figure 6-1. Molniya 1 Satellite

6.2 STATSIONAR (Refs. 318-332)

The Molniya satellites all use elliptical, high inclination orbits. However, since 1969 the U.S.S.R. has discussed plans for a communication satellite called Statsionar, which would be placed in the synchronous equatorial orbit. The first announcements indicated a launch of Statsionar at the end of 1970. Actually, in March 1974, Cosmos 637 was the first Soviet satellite put into synchronous equatorial orbit. Although not named as a predecessor of Statsionar, it has generally been assumed to be such. Molniya 1S was launched into synchronous orbit on July 29, 1974. The name and announcement clearly indicated that it was a communication satellite. The S in the satellite name apparently stands for synchronous or Statsionar.

In the second half of 1975 the U.S.S.R. released some details of the Statsionar system. The plans include ten satellites, designated Statsionar 1 to 10, for telephony and telegraphy and for distribution of television programs to Orbita-size earth stations. These satellites operate in the 5.7-to 6.2-GHz and 3.4-to 3.9-GHz bands. Figure 6-2 shows the location and service areas of these satellites. While most of these satellites are positioned to serve the U.S.S.R. and neighboring countries, the system does provide global coverage. Coverage of the U.S.S.R. itself requires at least two satellites because the geography is such that the entire country cannot be seen from any one point in synchronous equatorial orbit.

The 1975 announcements also included another satellite, Statsionar T, for television broadcasting to earth stations smaller than the Orbita type. This satellite has an uplink at 6.2 GHz and a downlink at 714 MHz.

All of the Statsionar satellites announced in 19`5 were to have been launched by 1980. Statsionar launches began at the end of 1975 and have continued, with the satellites being given several names. All synchronous orbit launchings through mid 1983 are listed in Table 6-2. In almost every case, the satellite orbit had an inclination less than 1 deg and a low eccentricity. As these satellites were launched, they were named in three

series: Raduga, Ekran, and Gorizont. These satellites were positioned in the various Statsionar locations, and it now appears that Statsionar is an orbital position designator rather than a satellite name.

The Statsionar satellites are associated with several networks of ground stations. These include the Orbita, Orbita-RV, Ekran, and Moskva networks. Their functions include sound and television broadcasting, telephone, and distribution of newspaper columns (presumably for remote printing). The Moskva stations, intended to be much simpler than Orbita stations, use 8-ft diameter antennas, in contrast to 40-ft for Orbita. The basic function of both the Ekran and Moskva networks is to expand the population served by television. In 1977 the U.S.S.R. claimed to have 70 Orbita and 60 Ekran stations in operation, with plans for more than 1000 Ekran stations.

The Intersputnik network for international communications began with use of Molniya satellites but now uses Statsionar satellites. The Intersputnik network and organization includes most communist east European and Asian nations plus a few others with close ties to the U.S.S.R., such as Cuba. The ground stations are similar to those of the Orbita network.

6.2.1 Raduga

The first Raduga (Rainbow) was launched in December 1975, and identified as being the same as the previously announced Statsionar 1. The U.S.S.R. announced that the Raduga satellites are three-axis-stabilized and have sun tracking solar arrays. Other details of their design are unknown, but are assumed to be similar to the Molniya 3 design. The estimated capacity of a Raduga is roughly one television signal and up to one thousand duplex voice circuits, when used with 30-to 40-ft diameter earth station antennas.

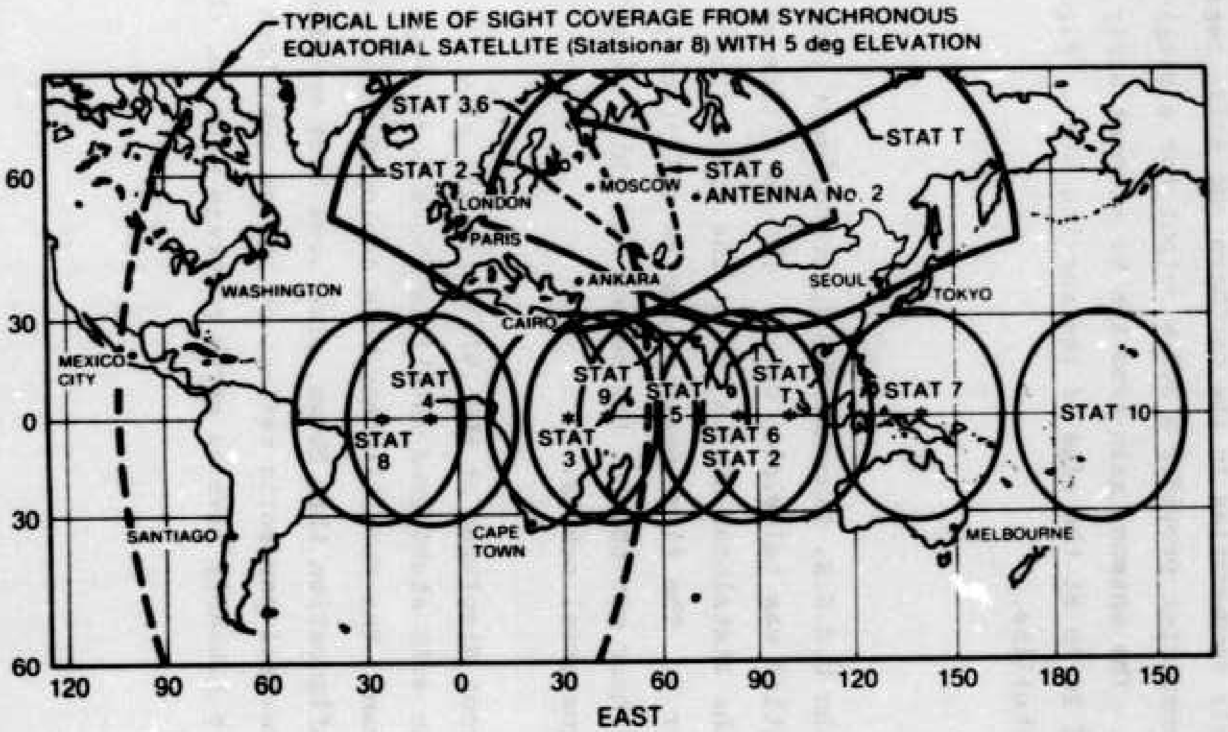
6.2.2 Ekran

The function of the Ekran (Screen), or Statsionar T, satellites is to broadcast television to small communities in the northern and Asian regions of the U.S.S.R. The Ekran transmitter provides a 200-W output for a single frequency modulated signal. The antenna gain from the 96 element array of helices is 33.5 dB peak and 26 dB at the edge of the service area. Figure 6-3 is a drawing of an Ekran satellite.

6.2.3 Gorizont

In December 1978 the U.S.S.R. launched the first Gorizont (Horizon) satellite. Its stated function was television relay. The satellite was not identified in relation to the Statsionar system, until the third launch which was identified as Statsionar 5. The first Gorizont had an elliptical, 11-deg inclination orbit with a 24-hour period, but the second and third satellites have typical synchronous equatorial orbits.

A photo of a Gorizont displayed at the 1979 Paris air show (Figure 6-4) reveals a three-axis-stabilized satellite whose body shape is very similar to that of Ekran. The satellite has both deployed solar arrays, of a somewhat different configuration than Ekran, plus some body mounted solar cells. The satellite has several parabolic reflectors and several horn antennas. The horn antennas probably have an earth coverage pattern, the reflectors a narrower beam.



NOTES: 1. Ellipses are nominal 1 dB coverage zones. Actual coverage may be modified by antenna pointing as shown for Statsionar 2 and 6
2. Statsionar T is primarily for television transmission to the U.S.S.R.
3. Directive antenna coverage shown for Statsionar 2, 3, 6 and T
4. Line of sight coverage to 5 deg elevation is global to near 77N with double and triple coverage at lower latitudes. See Statsionar 8 coverage to 5 deg elevation

Figure 6-2. Statsionar Deployment

Table 6-2. Statsionar Satellites

Name	Date	Longitude
Raduga 1	22 Dec 1975	66°E
Raduga 2	11 Sep 1976	86°E
Ekran 1	27 Oct 1976	a.
Raduga 3	24 Jul 1977	a.
Ekran 2	20 Sep 1977	a.
Raduga 4	18 Jul 1978	a.
Gorizont 1	19 Dec 1978	a.
Ekran 3	21 Feb 1979	97°E
Raduga 5	25 Apr 1979	a.
Gorizont 2	5 Jul 1979	90°E
Ekran 4	3 Oct 1979	a.
Gorizont 3	28 Dec 1979	a.
Raduga 6	20 Feb 1980	48°E
Gorizont 4	14 Jun 1980	13°W
Ekran 5	14 Jul 1980	82°E
Raduga 7	5 Oct 1980	25°W
Ekran 6	26 Dec 1980	63°E[b]
Raduga 8	18 Mar 1980	76°E
Ekran 7	26 Jun 1981	99°E
Raduga 9	21 Jul 1981	41°E
Raduga 10	9 Oct 1981	85°E
Ekran 8	5 Feb 1982	51°E[b]
Gorizont 5	15 Mar 1982	54°E
Ekran 9	16 Sep 1982	100°E
Gorizont 6	20 Oct 1982	90°E
Raduga 11	26 Nov 1982	35°E
Ekran 10	12 Mar 1983	99°E
Raduga 12	8 Apr 1983	84°E
Gorizont 7	30 Jun 1983	14°W
Raduga 13	26 Aug 1983	46°E
Ekran 11	30 Sep 1983	
Gorizont 8	30 Nov 1983	
Raduga 14	15 Feb 1984	
Ekran 12	16 Mar 1984	
Gorizont 9	22 Apr 1984	
Raduga 15	22 Jun 1984	

[a]Satellite is in a near circular orbit above or below synchronous altitude, or in an elliptical orbit with a period near 24 hours.
[b]Satellite is in a near synchronous orbit; longitude may drift as much as 2° per week.

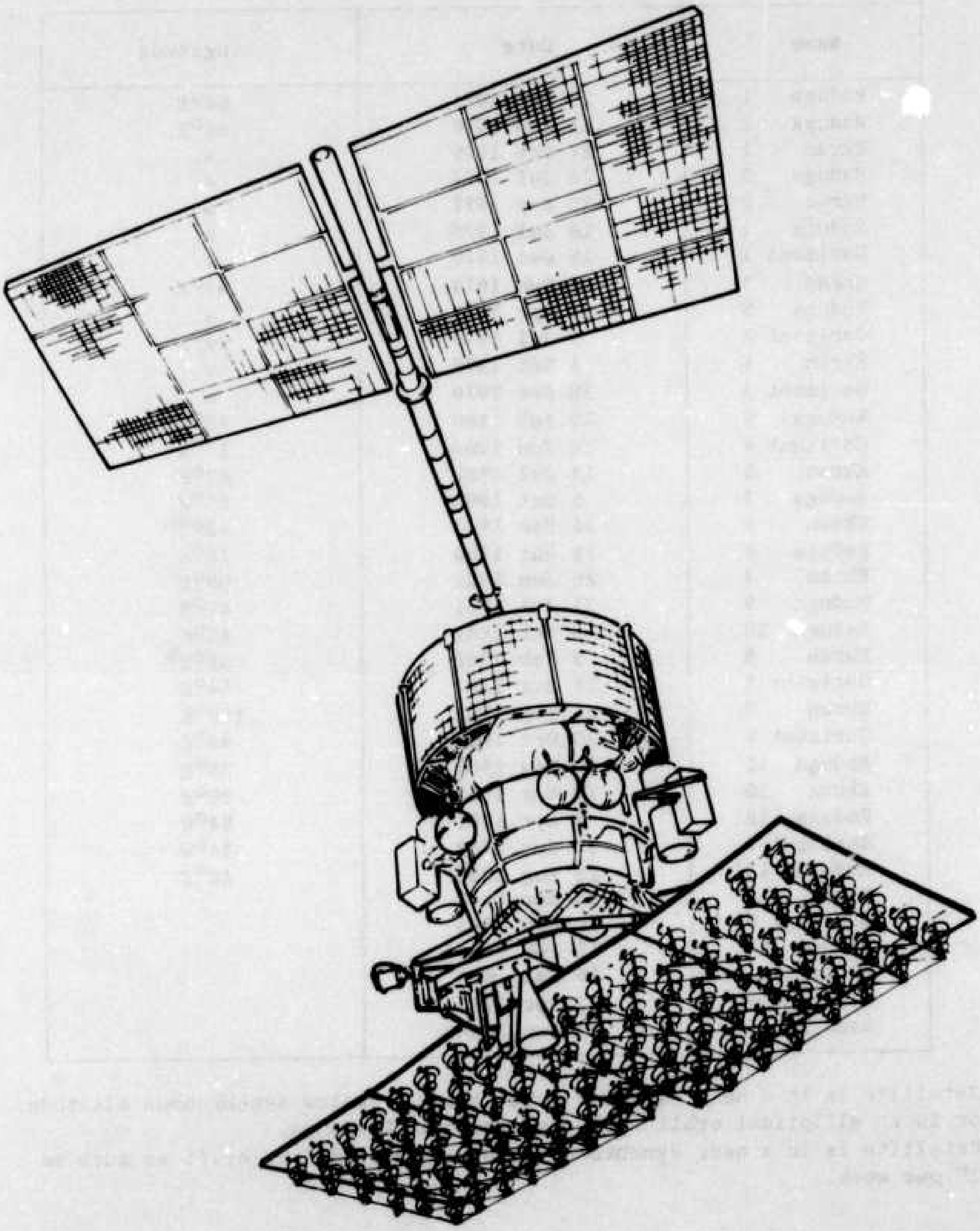


Figure 6-3. Ekran Satellite

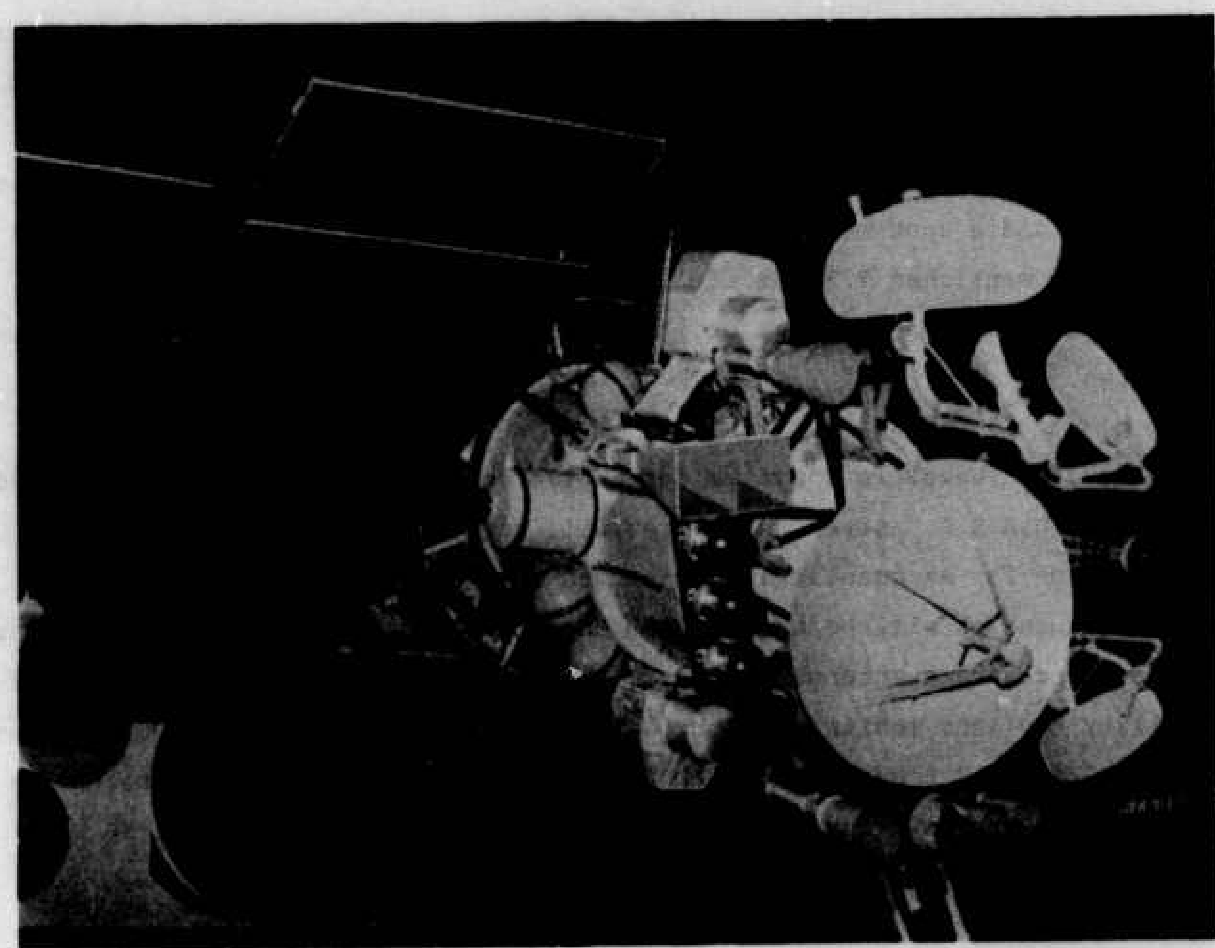


Figure 6-4. Gorizont Satellite

6.3 NEW SYNCHRONOUS SYSTEMS (Refs. 331-332)

During 1977 the U.S.S.R. announced plans for three new communication systems using satellites in synchronous orbit. Basic information is summarized in Table 6-3. The coincidences of different types of satellites at various longitudes suggest multiple payloads on a single bus, rather than separate satellites. Although the announced launch dates for all of these satellites were from 1979 to 1982, not one has yet been launched.

Gals (Tack) is a system intended for government service. It will use the 7.25- to 7.75- and 7.9- to 8.4-GHz bands. Gals satellites are described by the U.S.S.R. as having ten narrowband channels, with three or four receivers and transmitters. Antenna patterns include earth coverage, northern hemisphere, and a spot beam with about 5 deg beamwidth. A few non-technical reports have mentioned 7/8 GHz equipment on Raduga and Gorizont satellites. Whether the reports are wrong, or the equipment is related to the Gals system, is unknown.

Volna (Wave) is a system for mobile communications, and will be used only by the U.S.S.R. Seven satellites will have L-band equipment with two channels, one for aeronautical service and one for maritime service. The uplink frequencies will be around 1650 MHz, the downlink around 1540 MHz, both using earth coverage antenna patterns. Four satellites will also have a UHF capability for land mobile service. The uplinks will use 335 to 400 MHz, the downlinks 240 to 328 MHz. The peak antenna gain will be 14 dB for reception and 12 dB for transmission, with a total transmitter power of about 50 W.

The Luch* (Beam or Ray) system is intended for commercial communications, both domestic and international. These satellites will use the 11-and 14-GHz bands. The Luch system will have four satellites, supplemented by four similar satellites which are also called Luch, or sometimes Luch P.

---

*Or, Loutch.

Table 6-3. New Synchronous Satellites

Name	Frequency Band[a]	Longitude
Volna 1	UHF and L	25^{o}W
Gals 1	X	25^{o}W
Luch P1	11/14 GHz	25^{o}W
Volna 2	L	14^{o}W
Luch 1	11/14 GHz	14^{o}W
Volna 3	UHF and L	45^{o}E
Gals 2	X	45^{o}E
Luch P2	11/14 GHz	45^{o}E
Volna 4	L	53^{o}E
Luch 2	11/14 GHz	53^{o}E
Volna 5	UHF and L	85^{o}E
Gals 3	X	85^{o}E
Luch P3	11/14 GHz	85^{o}E
Luch 3	11/14 GHz	90^{o}E
Volna 6	L	140^{o}E
Luch 4	11/14 GHz	140^{o}E
Volna 7	UHF and L	170^{o}W
Gals 4	X	170^{o}W
Luch P4	11/14 GHz	170^{o}W

[a]UHF = 240 to 400 MHz
L-band = ~1540 to 1650 MHz
X-band = 7.25 to 8.4 GHz

7. DOMESTIC AND REGIONAL SATELLITES

Outside of the U.S.S.R., the first domestic (one-country) communication satellite system was that of Canada, which began operating early in 1973. Since that time, many countries have begun using domestic communication satellites (sometimes called domsats). Other countries have chosen a simpler approach to a domestic communications system by using their ground terminals with leased satellite capacity. Typically, the satellite capacity is leased from Intelsat. All specific domestic satellites are discussed in this section as well as systems using leased satellite services. In addition to these domestic systems, there are a few regional (multiple-country) satellites which are also described here. These domestic and regional systems are the fastest growing application of communication satellites at present, accounting for the majority of communication satellite programs in the western world. This fast growth will certainly continue through the entire decade.

Section 7.1 describes the Canadian satellites. Sections 7.2 through 7.5 describe various types of U.S. satellites. Sections 7.6 through 7.11 describe the European multination and single nation programs. Section 7.12 is on Japanese satellites. The remainder of Section 7 covers other national and regional programs and the Intelsat leases.

7.1 CANADA (Refs. 137, 333-335)

In 1969 the Canadian government established the Telesat Canada Corporation. The purpose of Telesat is to provide domestic communication services using satellites. Canada has excellent microwave communication facilities, but they are concentrated primarily in the heavily populated region along the Canadian-U.S. border. In the more northerly regions of Canada, there are hundreds of smaller towns and outposts not served by microwave. Their contact with each other and with the commercial and governmental centers in the south depended on radio-telephone and aircraft services. The radio communication facilities had been difficult to provide and unrealiable. The Telesat system now provides television and telephone service to many of these remote places as well as supplementing terrestrial systems for high density traffic links in southern Canada.

The Telesat system began operations at the beginning of 1973 following the launch of the first Anik satellite. (Anik is the Eskimo word for brother.) As plans developed for newer satellites, the first three satellites were designated the Anik A series. The satellites provided all types of communication services throughout Canada. A single Anik B satellite supplemented the A series and provided additional experimental channels. The Anik D series has started to replace the A and B satellites. The Anik C satellites are also in use but have a different function, which is to augment terrestrial communications on high traffic density paths.

7.1.1 Anik A (Refs. 137, 335-348)

The Anik A satellites were spin-stabilized with a single despun communications antenna. All equipment was mounted within the spinning body. The antenna was a five-ft diameter framework to which was attached a lightweight mesh that is optically transparent but reflective at the communication frequencies. A multiple element feed horn illuminated the reflector so that the antenna beam was shaped to match the Canadian land mass. This satellite is shown in Figure 7-1.

The Anik A communication subsystem (Figure 7-2) had 12 channels and was derived from the Intelsat IV communication subsystem. It had redundant receivers common to all channels and a single 5-W TWT for each channel. Each channel could handle one television signal or as many as 960 one-way telephone circuits. Enough prime power was available to operate all 12 channels initially and up to 10 during eclipse and later in the orbital life. Although the TWTs are not redundant, it was expected that 10 of the 12 would still be operable at the end of the seven-year design life. In practice, approximately 7-1/2 years after the first launch and seven years after the second, each satellite had six TWT "failures", which were defined by about 6 dB loss of gain. Additional details of the satellite and the communication subsystem are given in Table 7-1.

Anik A-1 was launched in November 1972 and became operational in January 1973. Initially, seven or eight channels were in full-time use, with other channels in use occasionally. Anik A-2 was launched in April 1973, primarily as an on-orbit spare for Anik A-1. Some channels were leased to U.S. communications companies for domestic operations prior to the launching of the U.S. satellites. Although the Anik A antenna pattern was optimized for Canada, the channel capacity between two terminals in the middle or northern latitudes of the U.S. was still about 60 percent of the capacity achievable between Canadian terminals.

Anik A-3 was launched in 1975 and soon became the primary operational satellite replacing Anik A-1. The Anik A-1 and A-2 satellites provided redundancy as well as channels for occasional transmissions. In July 1979 Anik B became the primary operational satellite. In 1980 Anik A-2 was moved to the same longitude as Anik A-3. This maximized, at one location, the number of channels available for spare and occasional use. (The single location minimized the number of ground terminal antennas required.) Since the launch of the first Anik D in 1982, the Anik A satellites' role has been greatly reduced.

7.1.2 Anik B (Refs. 90, 94, 333-334, 336, 349-355)

Anik B is a single satellite similar in design to the Radio Corporation of America (RCA) U.S. domestic satellites. It has three-axis stabilization and solar arrays that deploy in orbit (Figure 7-3). Anik B has two communication subsystem, each with its own antenna. One, using 4 and 6 GHz is identical to that of the Anik A satellites except that the TWT power has been doubled, increasing the ERP by 3 dB, and the G/T has been increased 1 dB. The second subsystem (Figure 7-4) operates at 12 and 14 GHz. It makes extensive use of hardware developed and tested in the CTS program, and has six channels, four TWTs, and four regional transmitting beams. Together, the four beams cover all of Canada (Figure 7-5). A number of switches provide flexibility in assigning channels to the regions and minimizing loss of coverage resulting from TWT failures. The receiver is connected to a single Canadian coverage beam.

Anik B was launched in December 1978. In July 1979 traffic from Anik A-3 was transferred to the 4/6-GHz subsystem. By the middle of 1983 this subsystem was still handling a considerable amount of traffic. The 12/14-GHz subsystem was leased to the government's Department of Communications. It was used to continue some of the experiments begun with CTS, and to provide preoperational experience for Anik C services. Anik B details are given in Table 7-2.

7.1.3 Anik C (Refs. 334, 336, 354-359)

Anik C is a spin-stabilized satellite that is designed for launch by either a Delta vehicle or the Space Shuttle. When in orbit, the antenna is deployed from one end of the satellite, and a cylindrical solar panel is extended at the opposite end. Within this panel is the cylindrical body of the satellite, which is also covered with solar cells except for a mirrored band that is a thermal radiator. The combination of the two arrays provides adequate power for the mission while allowing a compact launch configuration.

The two panels spin together in orbit as a rigid body. The relative position can be varied slightly by ground command to balance the satellite to help maximize antenna pointing accuracy. Figure 7-6 is a picture of Anik C.

The communication subsystem (Figure 7-7) has 16 repeaters and uses the 12- and 14-GHz bands. Both this subsystem and the antenna are mounted on a despun platform within the satellite body. Each repeater has a single TWT and the satellite has four spare TWTs. The TWTs are connected in a ring arrangement so that the spares are available to all channels. The repeaters occupy the 500-MHz allocation twice by means of orthogonal polarizations for both transmission and reception. The antenna is composed of two surfaces, each transparent to one polarization and reflecting another. These surfaces are slightly offset from each other to allow separate feed networks for each polarization.

The channels may be connected in various ways to the four regional transmitting beams. There is a single receive beam. For both reception and transmission the beams cover only the southern half of Canada (Figure 7-5). The reason for this is that Anik C is used to interconnect only the urban centers of Canada. The use of 12 and 14 GHz will allow the ground terminals to be placed inside cities without interference between the satellite system and terrestrial microwave facilities. In typical use, the Anik Cs will have one 91-Mbps data stream or two FM television signals per satellite repeater.

Table 7-3 is a summary of the Anik C design. Anik C-3 was launched on Shuttle flight 5 in November 1982. The second satellite was launched in June 1983 and the third is scheduled for a 1984 launch.

7.1.4 Anik D (Refs. 335-336, 360)

The Anik D satellites are replacements for the Anik A satellites and eventually also for Anik B. The satellite structure, support subsystems, thermal radiator, and deployable solar array are almost identical to those of Anik C (Figure 7-6).

The major difference between the two types of satellites is the communication subsystem (Figure 7-8). Anik D has twenty-four repeaters in the 4- and 6-GHz bands. This is twice the number contained in an Anik A satellite and is accomplished by dual polarized reception and transmission. The antenna pattern is shaped to provide coverage of all of Canada, the same as Anik A. However, the TWT output power is twice that of the earlier satellites, thus allowing equal service to smaller ground terminals.

Details of the Anik D satellites are given in Table 7-4. The satellites are being built by Spar Aerospace, a Canadian company, which is a subcontractor on many other satellites (including Anik C) of similar design. The first Anik D was launched in August 1982 and is in use. The second is scheduled to be launched in 1985, at the end of the Anik B lifetime.

7.1.5 Telesat System (Refs. 336, 342-347, 352, 358-366)

The Telesat system handles a wide variety of traffic, reflecting the diverse needs of the country. Television distribution is a major function of the system. Transmissions are FM with one video plus several audio signals per satellite repeater, except for Anik C (two per repeater). Telephony is another major function. FDMA has been in use since the beginning, with FDM voice channels on high density routes and SCPC on low density routes. On Anik C voice channels are all transmitted digitally. Use of TDMA began in the late 1970s and has increased, but is not yet as common as FDMA. Data transmission also exists in the system at rates from 2.4 kbps to greater than 1 Mbps.

The Telesat system includes six types of ground terminals for communications plus three TT&C terminals. The characteristics of these terminals are listed in Table 7-5. The heavy route terminals, with 97-ft antennas, are equipped for all communications services, and each has several transmitters and receivers for handling multiple simultaneous links. In addition, these terminals have a complete set of TT&C equipment. The network TV terminals are primarily for transmission and reception of high quality TV. Northern telecommunications terminals provide voice links with the heavy route

stations and reception of television for local rebroadcasting to home receivers. Remote TV terminals receive television transmissions for local rebroadcast, and they have the capability of being expanded to provide two-way telephone service. This capability has been used in several terminals subsequently to their initial installation. The thin route terminals provide limited two-way telephone service and can be upgraded to add television reception capability.

Initially, early in 1973, the system had 36 communication terminals. Since then more than 100 other terminals have been installed, mostly of the remote TV and thin route types. Over half of these new terminals are located in the northern territories of Canada. Because of the large number of terminals in remote locations, considerable effort was made to keep them inexpensive. Thus, only the heavy route and TT&C terminals require full-time manning. Also, since the satellites have stationkeeping to ± 0.1 deg or better, only these two types of terminals require automatic tracking.

Satellite and network control for the Telesat system is accomplished from a control center in Ottawa. Satellite control is accomplished primarily using the heavy route terminal near Toronto and the collocated TT&C terminals. The heavy route terminal is pointed at the primary satellite, and a TT&C terminal is pointed at each of the other satellites.

The Anik C system became operational in 1983, with ten main terminals in the major cities. These terminals have 25-ft antennas, with automatic step tracking. Six are equipped for telephone and television transmission and reception, and four for television only. They have a G/T of 35 dB^{o}/K and an ERP of 74 to 82 dBW. Additional 15-ft antennas will be installed as needed for television transmission and reception or for reception only, or for transmission and reception of 45 Mbps digital data streams.

Figure 7-1. Anik A Satellite

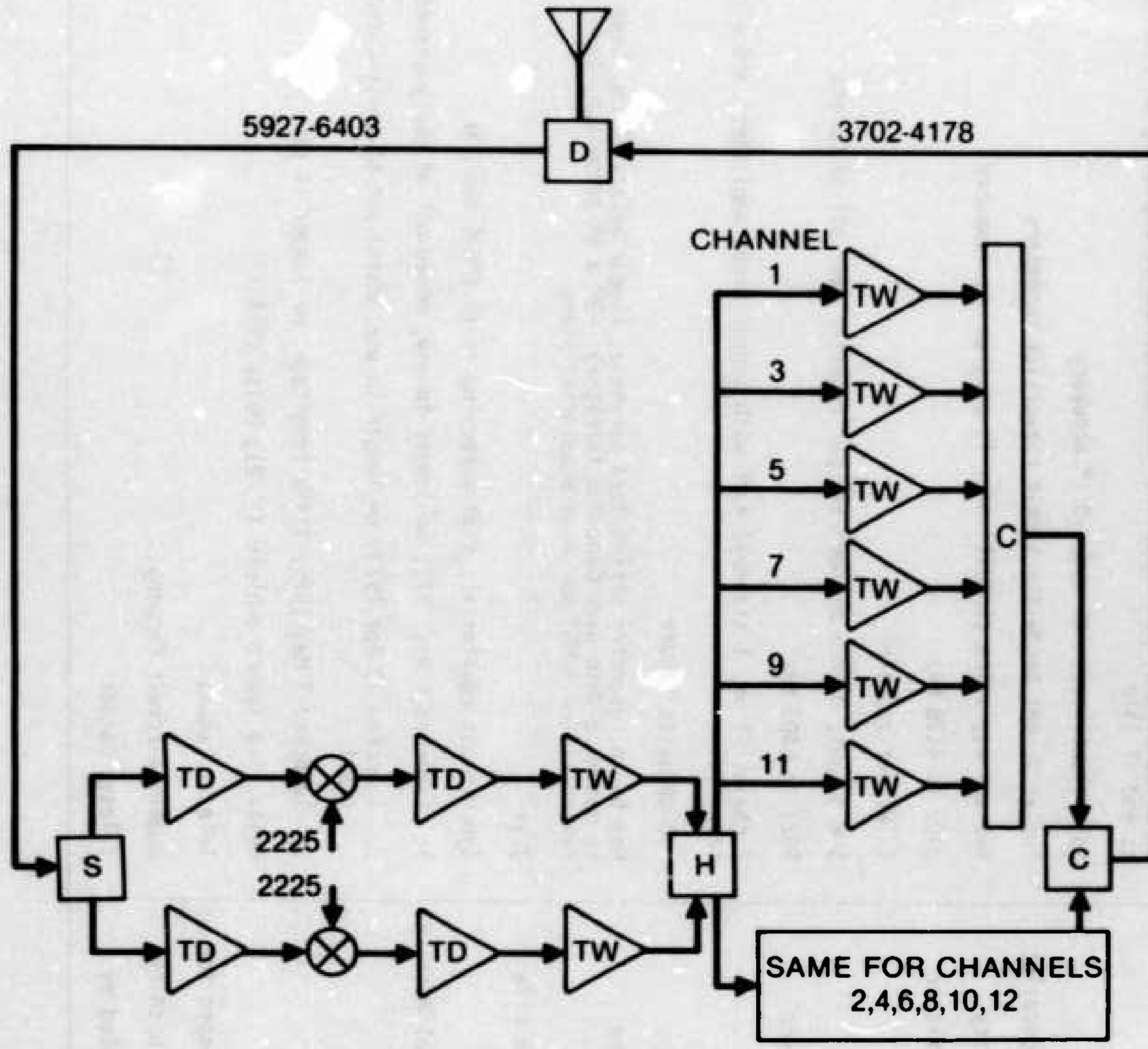


Figure 7-2. Anik A Communication Subsystem

Table 7-1. Anik A Details

Satellite	Cylinder, 75-in. diameter, 67-in. high, overall height 139-in.
	655 lb in orbit, beginning of life
	Solar cells and NiCd batteries, 330 W maximum at beginning of life, 260 W at end of life
	Spin-stabilized, 100 rpm, $\pm 0.1^{\circ}$ accuracy
Configuration	Twelve 36-MHz bandwidth single conversion repeaters
Capacity	960 one-way voice circuits of 1 TV program per repeater
Transmitter	3702 to 4178 MHz
	1 TWT per repeater
	5-W output, 33-dBW minimum ERP per repeater over all of Canada
Receiver	5927 to 6403 MHz
	2 chains (1 on, 1 standby) each with tunnel diode amplifiers and a low level TWT
	7.8-dB noise figure
Antenna	One 60-in. diameter offset feed parabola, linear polarization, beam shaped to maximize gain over Canadian territory, $\sim 3^{\circ} \times 8^{\circ}$ beamwidth, beam center tilted 7.85° north of equatorial plane
Design Life	7 yr
Orbit	Synchronous equatorial; stationkeeping to $\pm 0.1^{\circ}$N-S and E-W
Orbital History	1: Launched 9 Nov 1972, no longer in use, moved out of geosynchronous orbit
	2: Launched 20 Apr 1973, no longer in use, moved out of geosynchronous orbit
	3: Launched 7 May 1975, 114°W longitude, no longer in use
	Delta 1914 launch vehicle (1, 2); Delta 2914 (3)
Developed for	Telesat Canada
Developed by	Hughes Aircraft Company
Operated by	Telesat Canada

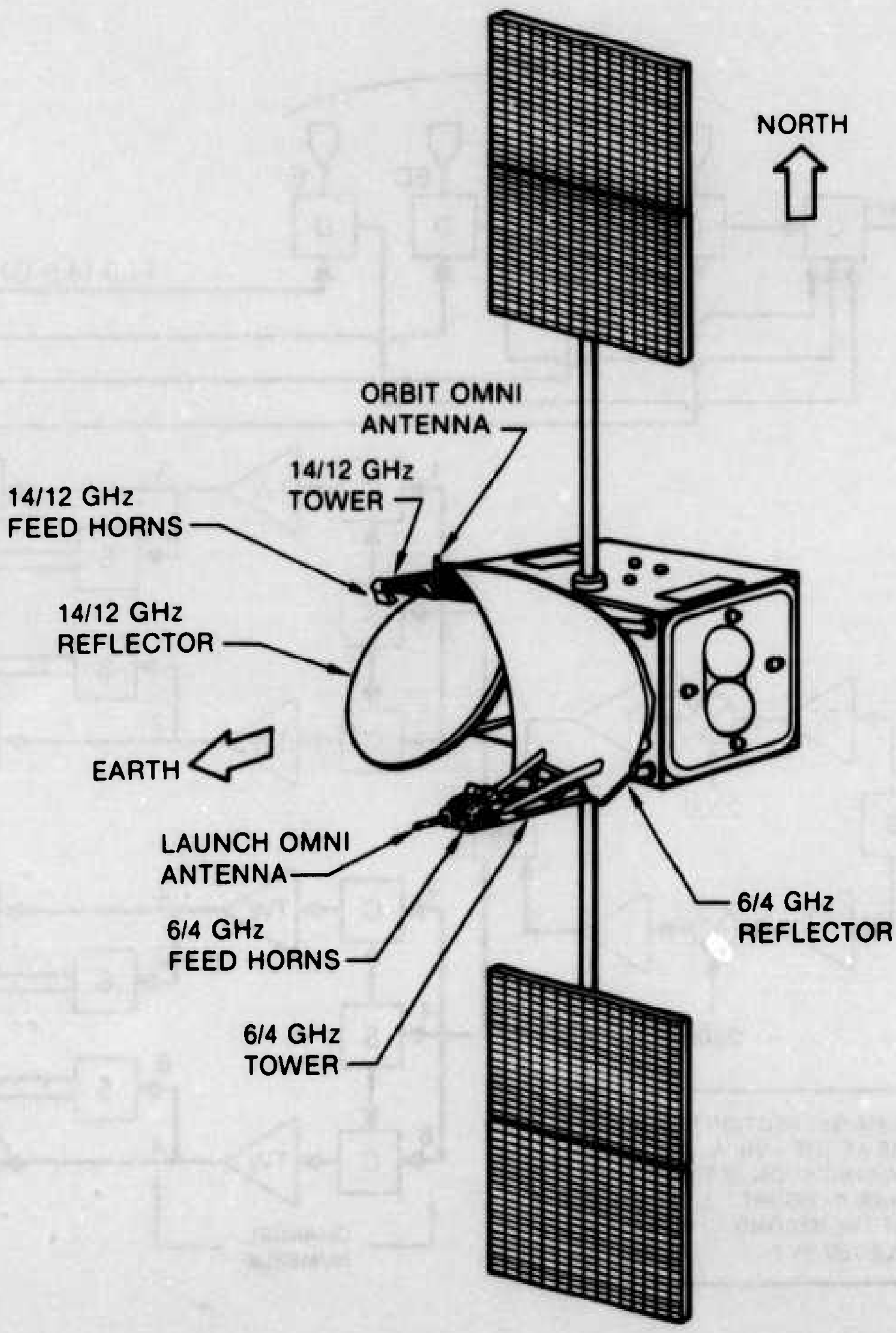


Figure 7-3. Anik B Satellite

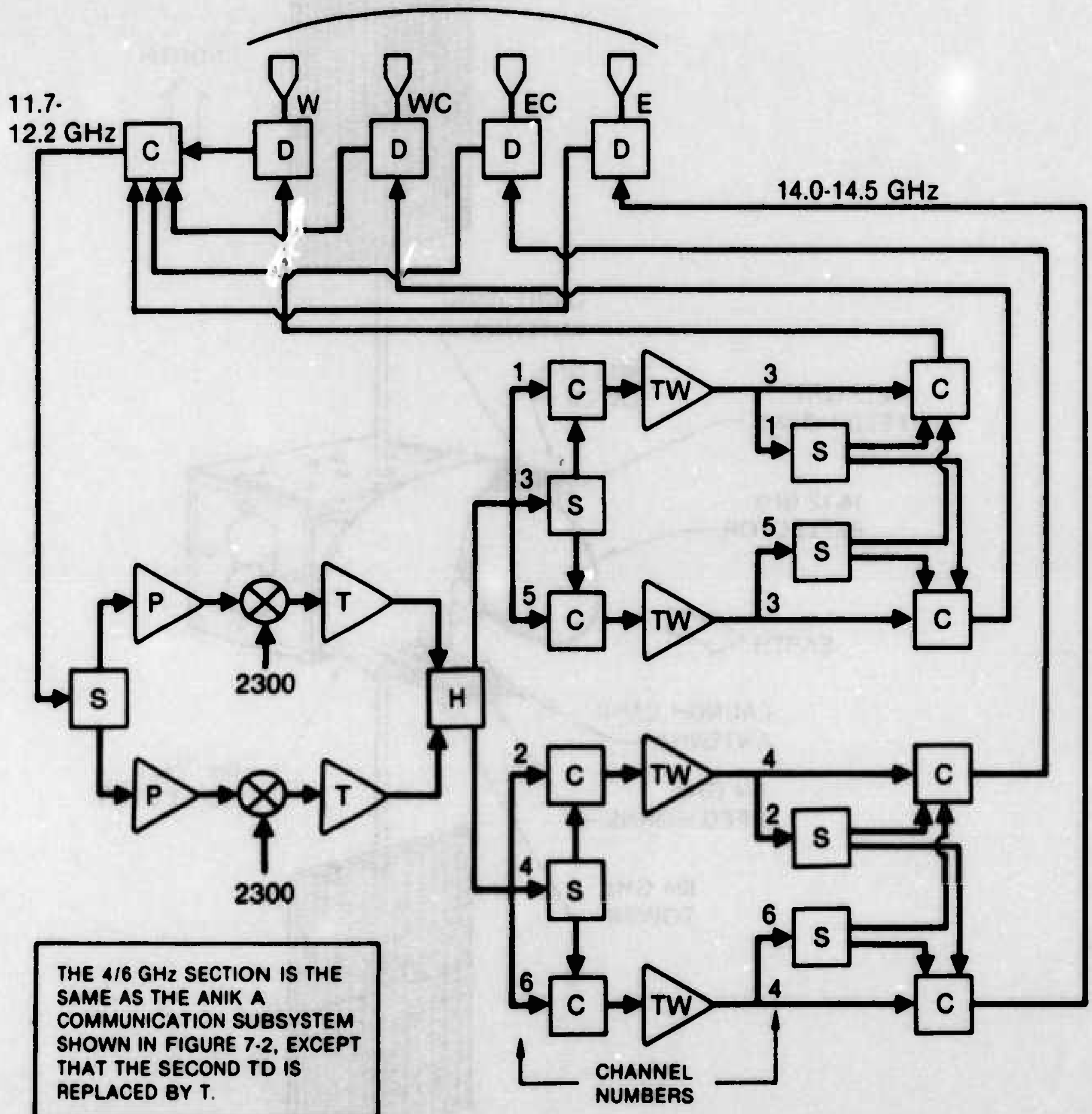
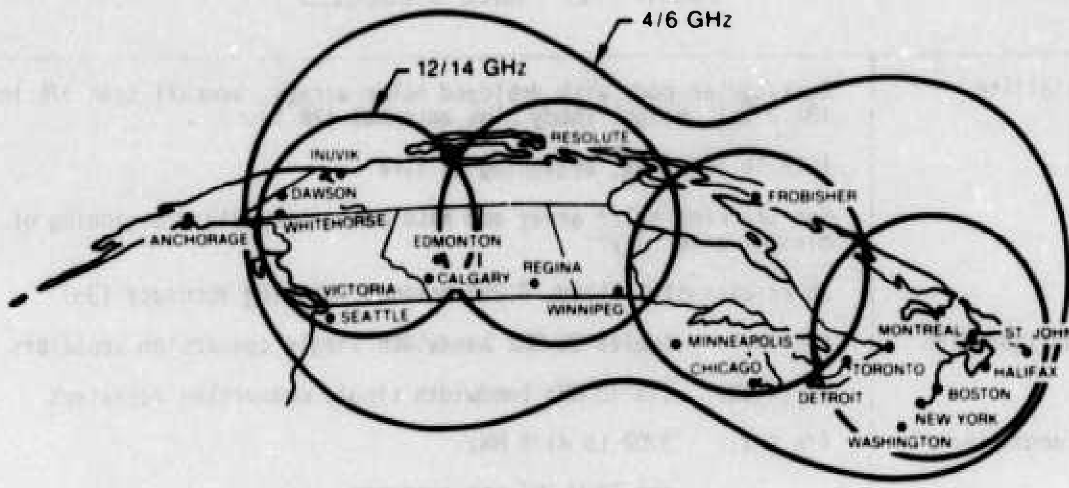
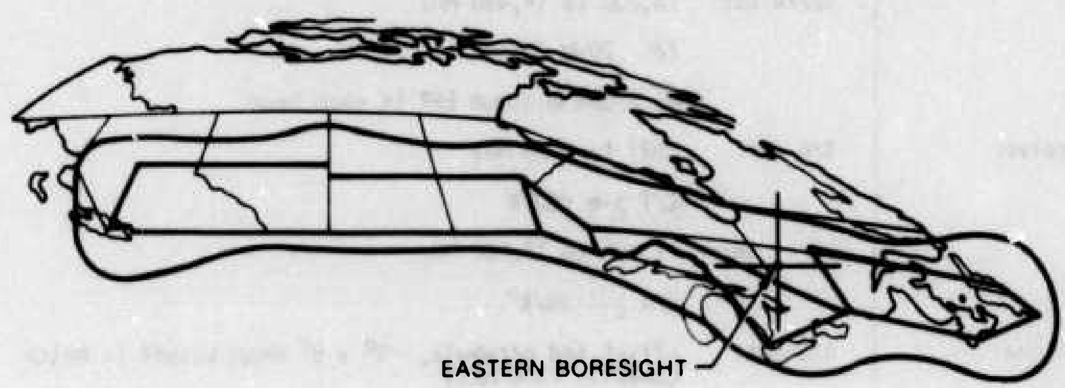


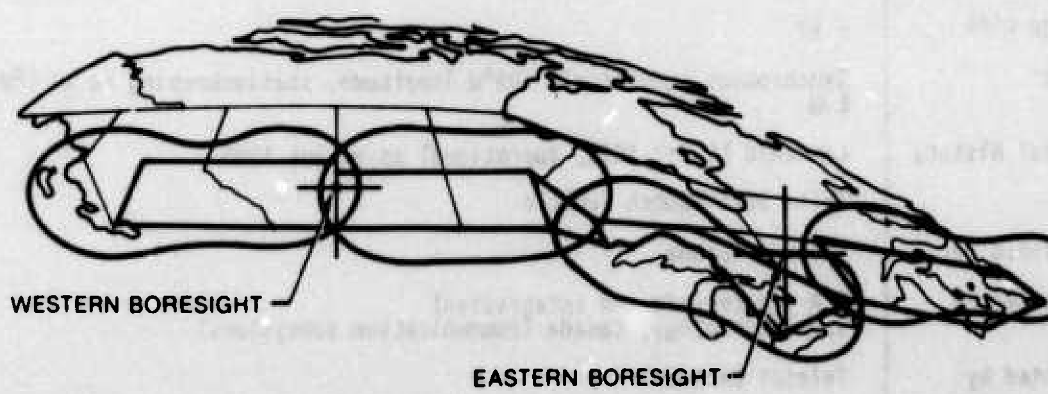
Figure 7-4. Anik B 12/14-GHz Communication Subsystem



ANIK B (4/6-GHz transmit and receive and 12/14-GHz transmit)



ANIK C (receive)



ANIK C (transmit)

Figure 7-5. Anik B and C Antenna Patterns

Table 7-2. Anik B Details

Satellite	Rectangular body with deployed solar arrays, overall span 376 in. (31.3 ft), height (body plus antenna) 128 in.	
	1016 lb in orbit, beginning of life	
	Sun tracking solar array and NiCd batteries, 840 W beginning of life, 635 W minimum after 7 yr	
	Three-axis-stabilized, 0.25° antenna pointing accuracy (3σ)	
Configuration	4/6 GHz:	twelve 36-MHz bandwidth single conversion repeaters
	12/14 GHz:	six 72-MHz bandwidth single conversion repeaters
Transmitter	4/6 GHz:	3702 to 4178 MHz
		one 10-W TWT per repeater
		36-dBW minimum ERP per repeater over all of Canada
	12/14 GHz:	14,000 to 14,480 MHz
		four 20-W TWTs
		46.5-dBW minimum ERP in each beam
Receiver	4/6 GHz:	5927 to 6403 MHz
		G/T ≥-6 dB/°K
	12/14 GHz:	11,700 to 12,180 MHz
		G/T ≥-1 dB/K°
Antenna	4/6 GHz:	offset fed parabola, ~3° x 8° beam shaped to match Canadian land mass
	12/14 GHz:	offset fed parabola, ~36 in. x 48 in. one receive beam shaped to match Canada, four 1.8° x 2° transmit beams each covering one quarter of Canada, minimum measured gain over coverage areas 35.1 dB (transmit) and 29.4 dB (receive)
Design Life	7 yr	
Orbit	Synchronous equatorial, 109°W longitude, stationkeeping to ±0.1°N-S and E-W	
Orbital History	Launched 15 Dec 1978, operational as of Jul 1983	
	Delta 3914 launch vehicle	
Developed for	Telesat Canada	
Developed by	RCA (spacecraft and integration) Spar Technology, Canada (communication subsystems)	
Operated by	Telesat Canada	

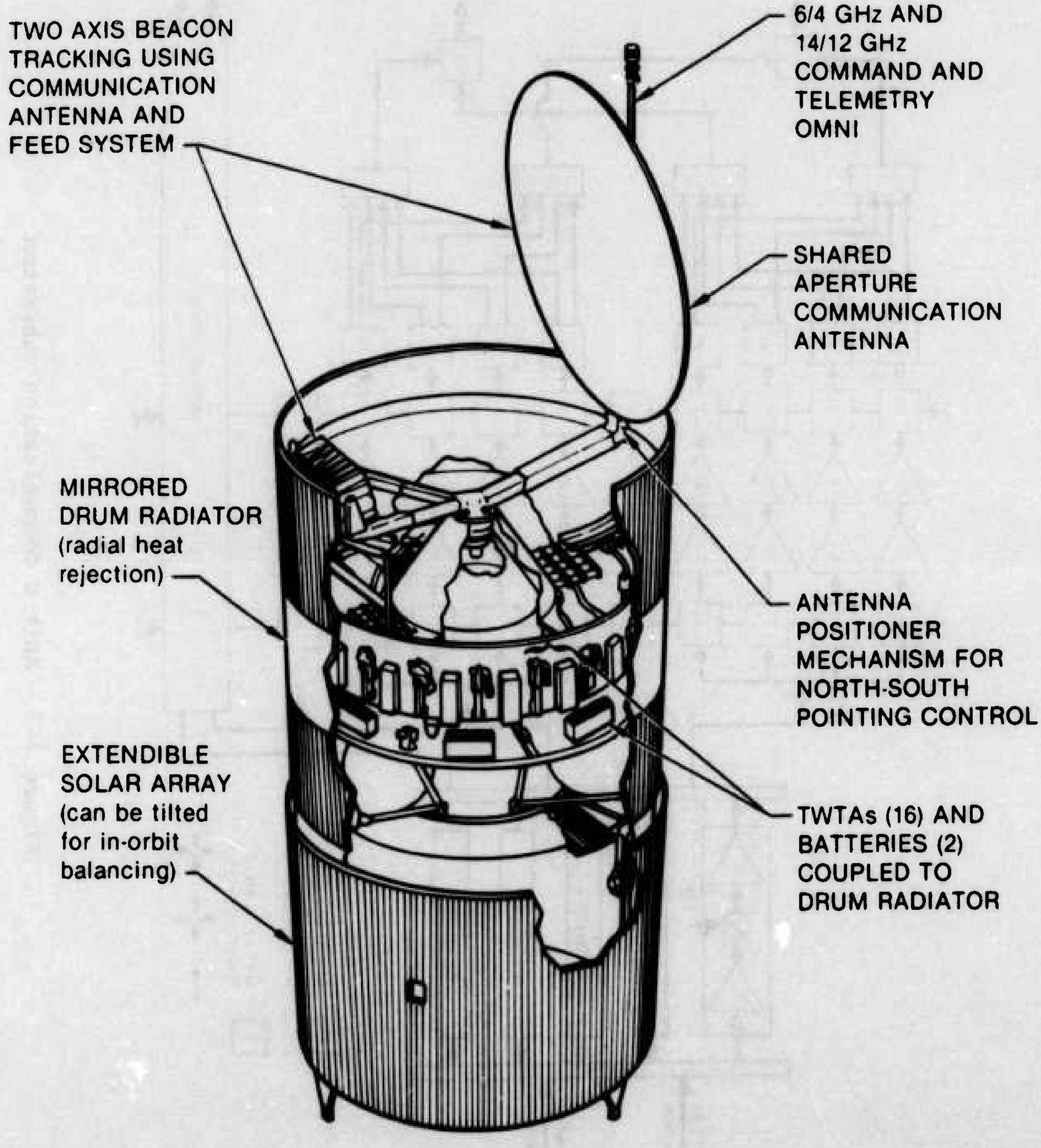


Figure 7-6. Anik C Satellite

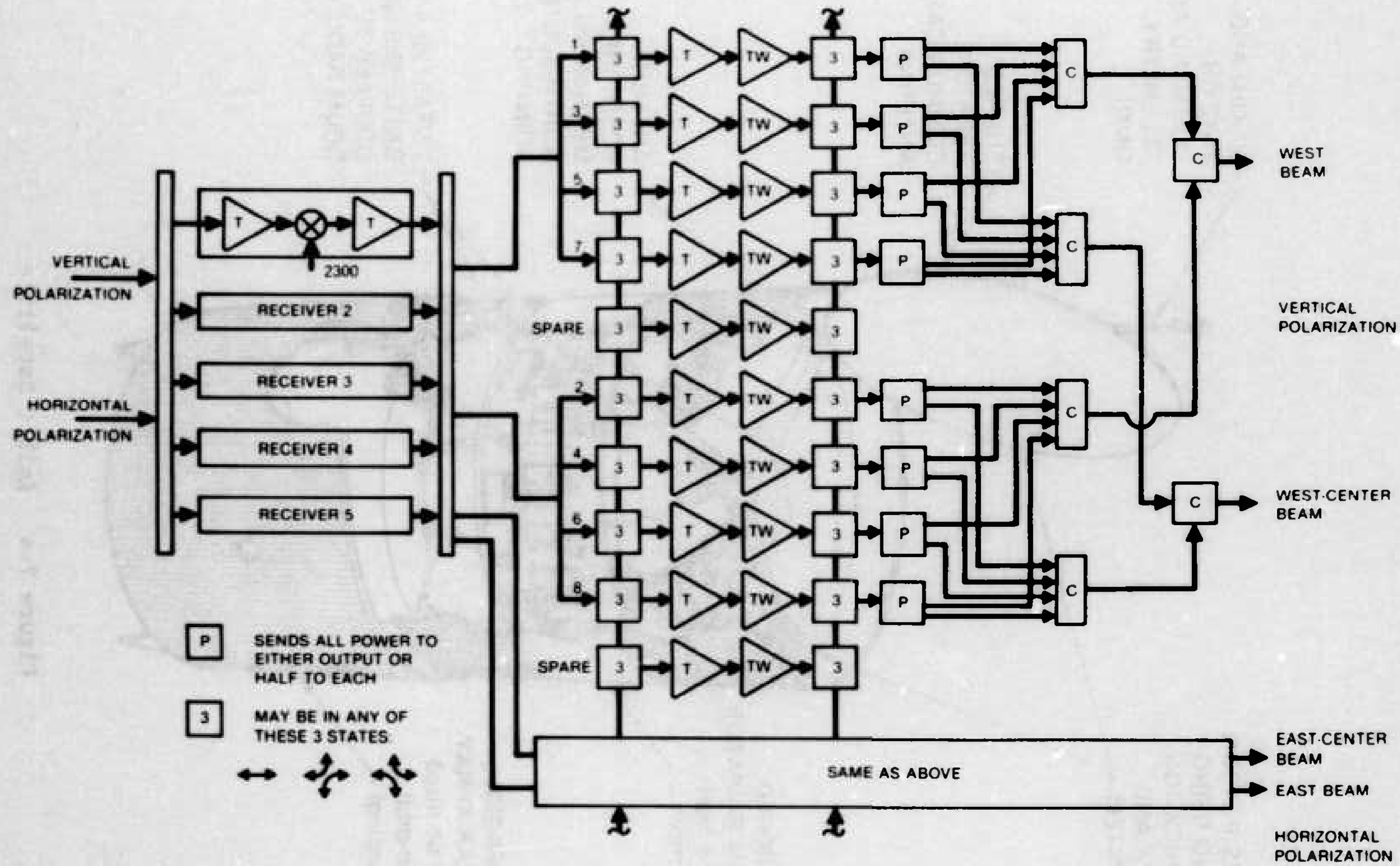


Figure 7-7. Anik C Communication Subsystem

Table 7-3. Anik C Details

Satellite	Cylinder, 85-in. diameter, 253-in. (21.1 ft) tall in deployed condition 1250 lb in orbit, beginning of life Solar Cells and NiCd batteries, 800 W end of life Spin-stabilized, gyrostat, antenna beam pointing to 0.02^o
Configuration	Sixteen 54-MHz bandwidth repeaters, dual polarization frequency reuse, horizontal polarization channel centers 13 MHz higher than vertical polarization
Capacity	91 Mbps (1344 voice channels) or 2 television programs per repeater
Transmitter	11.703 to 12.197 GHz One 15-W TWT per repeater plus 4 spares per satellite 47-dBW ERP per repeater using one antenna beam, 3 dB lower when output is split between two beams, 5.5-dB backoff when two television transmissions share a repeater
Receiver	14.003 to 14.497 GHz 2 active plus 3 spare receivers +2 $dB/^oK$ G/T
Antenna	One 72-in. diameter paraboloid, dual linear polarizations for both receive and transmit, 1 receive beam $\sim 1^o \times 8^o$, 4 contiguous transmit spot beams $\sim 0.8^o \times 2^o$ each, each pair of spot beams may be combined into an area beam $\sim 1.2^o \times 2^o$, beams aimed to cover southern half of Canada
Design Life	10 yr
Orbit	Synchronous equatorial, stationkeeping to $\pm 0.05^o$N-S and E-W
Orbital History	3: Launched 11 Nov 1982, 117.5^oW longitude, in use 2: Launched 18 Jun 1983, 112.5^oW longitude, in use 1: Launch scheduled in Jun 1984, will go to 107.5^oW longitude Shuttle launch vehicle (satellite design is also compatible with Delta 3910)
Developed for	Telesat Canada
Developed by	Hughes Aircraft Company (about 40% of the work is subcontracted to Canadian firms)
Operated by	Telesat Canada

Table 7-4. Anik D Details

Satellite	Cylinder, 85-in. diameter, 258 in. (21.5 ft) tall in deployed condition ~1400 lb in orbit, beginning of life Solar cells and NiCd batteries, 800 W end of life Spin-stabilized, gyrostat
Configuration	Twenty-four 36-MHz bandwidth repeaters, dual polarization frequency reuse
Capacity	960 one-way voice circuits or 1 TV program per repeater
Transmitter	3702 to 4198 MHz 1 TWT per repeater 10-W output, 36 dBW minimum ERP per repeater over all of Canada
Receiver	5927 to 6423 MHz Two active plus two spare receivers G/T $\geq$-6 dB/^{o}K
Antenna	One 72-in. diameter reflector, multiple feed horns to optimize beam shape for Canada, orthogonal linear polarizations
Design Life	10 yr
Orbit	Synchronous equatorial, stationkeeping to $\pm$0.05^{o}N-S and E-W
Orbital History	1: Launched 27 Aug 1982, 104.5^{o}W longitude, in use 2: Launch scheduled late 1984 Delta 3920 launch vehicle for 1, Shuttle for 2
Developed for	Telesat Canada
Developed by	Spar Aerospace with Hughes Aircraft Company as a major subcontractor
Operated by	Telesat Canada

Table 7-5. Canadian Ground Terminals

Parameters	Terminal Type[a]											
	HR	NTV	NTC	RTV	TR	FTV	Transportable	TT&C	HR(12/14)	MR(12/14)	TV(12/14)	TT&C(12/14)
Antenna												
Diameter, ft	97	33	33	26	26	12-15	12-26	15-36	25	15	25	15/36
G/T, dB/°K	37	28	28	26	26	20-22	<26	17-28	33	28.5	33	26/35
Transmitters												
Installed/Station	3-8	1-3	2	0[b]	2	0	0-2	2	2-8	1-2	2-3	2
ERP/Channel, dBW	83	83	73	0[b]	58	0	~54	85	~85	~85		81/91
Receivers												
Installed/Station	5-10	4	2-3	1-2	2	1	1-2	2	≥2	2	≥2	2
Antenna Steering	Step Track	Manual	Manual	Manual	Manual	Manual	Manual	Monopulse or Manual	Step Track		Step Track	Manual/ Monopulse
No-Break Standby Power	Batteries & Diesel	Batteries & Diesel	Batteries & Diesel	Batteries	Some have Batteries	Some have Batteries	Some have Batteries	Batteries & Diesel	Batteries & Diesel		Batteries & Diesel	Batteries & Diesel

[a]Terminal Types:
4/6 GHz:
- HR Heavy Route
- NTV Network Television
- NTC Northern Telecommunications (or Medium Route)
- RTV Remote Television
- TR Thin Route
- FTV Frontier Television
- TT&C Tracking, Telemetry, and Command

12/14 GHz:
- HR Heavy Route
- MR Medium Route
- TV TV Distribution
- TT&C Tracking, Telemetry, and Command

[b]Some RTV terminals have had a TR capability retrofitted.

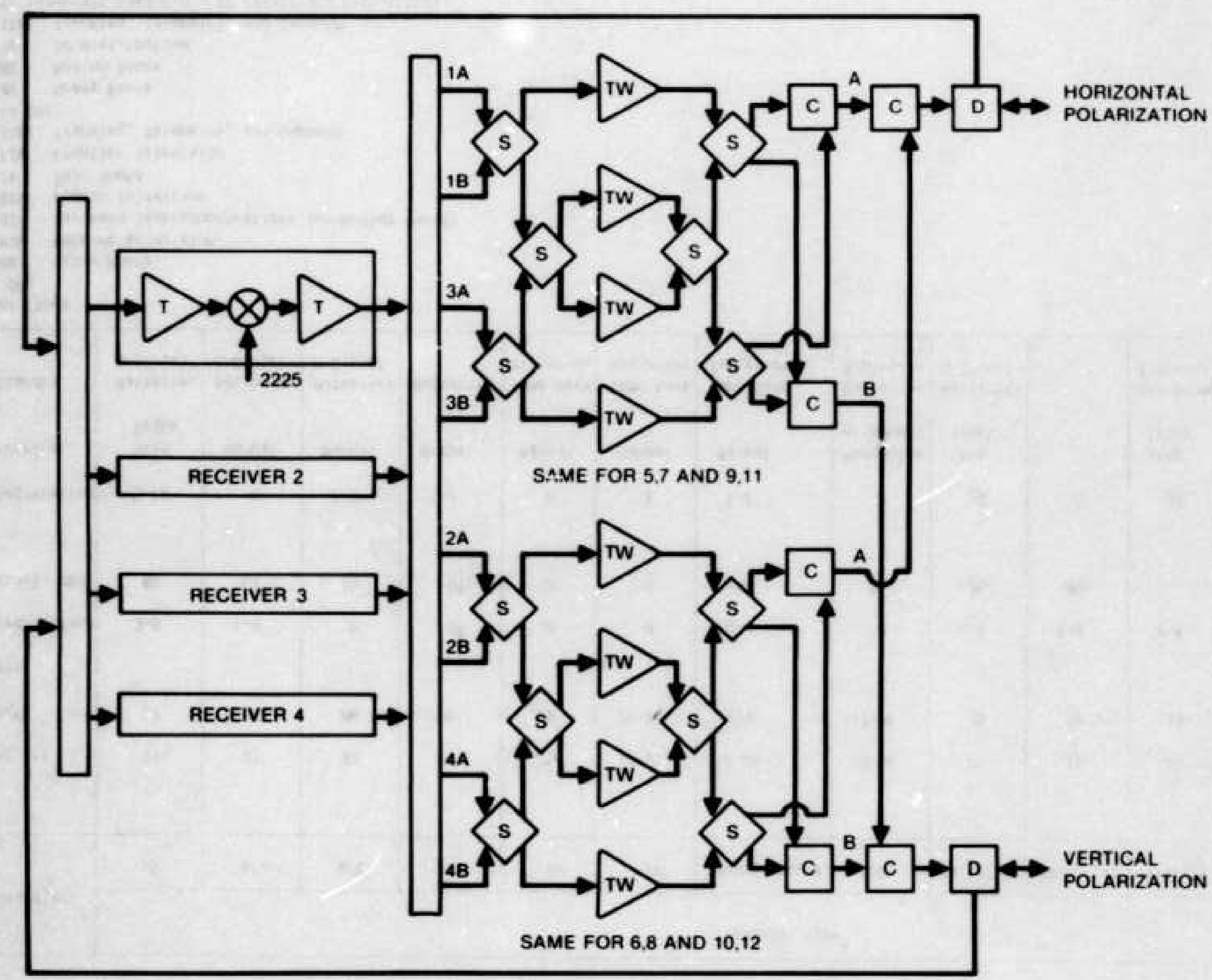


Figure 7-8. ANIK D Communication Subsystem

7.2 UNITED STATES (Fixed Terminal Systems)

This section describes the satellites of several systems that are, or will be, providing domestic communication services for the U.S. Together, these systems serve the continental U.S. (CONUS), Alaska, Hawaii, and Puerto Rico.

7.2.1 Overview (Refs. 137, 144, 367-380)

In September 1965, the American Broadcasting Company filed a request with the Federal Communications Commission (FCC) for authorization to operate a communication satellite system for distribution of network television. This application was returned by the FCC without comment, pending an inquiry concerning public policy questions related to the establishment of domestic communication satellite systems. This inquiry began in March 1966 with many diverse organizations presenting their views to the FCC. During the next few years many studies, opinions, system proposals, and experimental plans were submitted. In addition to the FCC inquiry, both the legislative and executive branches of the government studied domestic satellite systems. In 1968 a task force appointed by the President prepared a report favoring a limited pilot program. However, just at the time the report was published, a new administration was elected, and a new investigation was started. In January 1970, the study group issued a report favoring "open entry" for domestic satellite systems. Based on this report, the FCC in March 1970 invited applications for permission to construct and operate the systems. By the March 1971 deadline, eight applications were filed.

FCC action on these applications was prolonged by more comments, claims, and counterclaims. A tentative decision in June 1972 modified the open entry policy to require each applicant to show that it is financially and technically qualified and that the proposed service is in the public interest. This decision also placed specific restrictions on certain applicants. Following further arguments, a final FCC decision in December

1972 opened the way for processing of the applications. The FCC had allowed opportunities (after the March 1971 filing) for applicants to drop, modify, or combine applications. As a result, there were five active applications at the start of 1973. These applications were submitted by the following companies:

a. Western Union Telegraph Company
b. American Satellite Corporation
c. Hughes Aircraft Company and GTE Satellite Corporation
d. Comsat General Corporation and AT&T
e. RCA Globcom and RCA Alascom

Three approvals were required for each system, covering the satellite equipment, ground equipment, and system operations. By January 1974, all five applicants had received one or more of these approvals, and both satellite and ground equipment were being built. However, in February 1974 American Satellite Corporation canceled its order for three satellites because of lack of financing. Then, in April of the same year, AT&T and GTE announced plans to combine their systems using the satellites being developed for AT&T. At the end of 1974 the status of these applications was as follows:

a. Western Union Telegraph Company began operations in 1974.
b. RCA was developing its own satellites. (Initial operations began in December 1973 with satellite capacity leased from Telesat Canada.)
c. AT&T was proceeding toward operational status, with Comsat General developing satellites for the system.
d. GTE had dropped plans for its own system, preferring joint operations with AT&T; the next year it became a user of the AT&T system, rather than a joint owner.
e. American Satellite Corporation was leasing satellite capacity from Western Union.

The RCA and AT&T systems began operations in 1976. By the fall of that year each had two satellites in orbit, as did Western Union*. In the same year, CML Satellite Corporation, a combination of two of the eight March 1971 applicants, reorganized as Satellite Business Systems (SBS). FCC approval was received in 1977 and the first SBS satellite was launched late in 1980. The system became operational in March 1981. At the end of 1980 nine satellites were in orbit: three each for the Western Union and AT&T systems, two for RCA and one for SBS. In addition, a third RCA satellite was destroyed just before reaching the synchronous orbit.

During the first few years after Western Union and RCA began operations, the demand for satellite capacity was quite low. About 1978 the demand began growing very quickly. By early 1980 the FCC had several applications to consider, some for expansion of existing systems and some for new systems. Those which were filed before May 1 of that year were considered together and approved in December. New systems that were authorized are Hughes Communications Inc. (HCI), Southern Pacific Communications Company (SPCC), and GTE Satellite Corporation (GSat). The situation at the end of 1980 is summarized in the first three columns of Table 7-6. The number of satellites authorized for construction exceeds the number of authorized locations because the satellites under construction include replacements for older satellites and ground spares.

In 1981 the FCC began a broad review of the domestic satellite licensing policy. The purpose of this review was to formulate the best method of allocating orbital and spectral resources to what was foreseen as an ever growing demand. The primary emphasis was on the orbital spacing of satellites.

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*Prior to the development of these systems, the Intelsat system was used for satellite communications between CONUS and Hawaii, Alaska, and Puerto Rico. The Intelsat terminal in Alaska became a part of the RCA system and the terminal in Puerto Rico became a part of the AT&T system. Although these systems serve Hawaii, the Intelsat terminal there has remained in the Intelsat system to link Hawaii with many Pacific nations and islands.

In 1970 five-deg spacing between satellites was assumed necessary to prevent interference. In 1974 this was reduced to four deg. In the 1980 decisions four deg was used for satellites using the 4- and 6-GHz bands and three deg for those using the 12- and 14-GHz bands.

The review begun in 1981 was not completed until April 1983. At that time the orbital spacing was reduced to two deg for both frequency bands, with implementation of this spacing to proceed over the next few years. This action almost doubled the number of potential satellite locations in orbit. However, most of these locations were assigned to new satellites and new systems authorized in concluding the review. The new authorizations, covering all applications received by May 1982, included additional satellites for several systems plus five new systems. The new systems are RCA, using the 12- and 14-GHz bands in addition to the current 4- and 6-GHz satellites, American Satellite Corporation, United States Satellite Systems, Rainbow Satellite, and Advanced Business Communications. American Satellite is well established in the business, having operated a growing number of ground terminals with the Westar satellites since 1974. The latter three companies must prove, by the end of 1983, their capability to carry out the projects or else lose their authorizations.

In addition to these systems, several more applications are pending before the FCC. These include a set of 12- and 14-GHz satellites for HCI and systems of Ford Aerospace Satellite Services, Cablesat General, and others. It is likely that, in repetition of what happened in the early 1970s, not all of the authorized or proposed systems will be completed.

The following sections provide information on all of the systems currently operating or authorized, and some of those proposed. Information on U.S. TV broadcast systems is presented in Section 7.5.

7.2.2 Western Union (Refs. 381-406)

The first set of Western Union satellites are Westar I, II, and III (Figure 7-9). They are nearly identical to the Canadian Anik A satellites. The satellite is spin-stabilized; the body and all equipment within spins - only the antenna is despun. The antenna is five feet in diameter and is fed by an array of three horns that produce a pattern optimized for CONUS. A fourth horn provides a lower level beam for Hawaii. The communication subsystem has 12 channels, with a bandwidth of 36 MHz each. Each channel has a single TWT. The satellite has no spare TWTs, but it was expected that 10 of the 12 channels would be operable at the end of the satellite's seven-year life which was true for both Westar I and II in 1981. Figure 7-10 shows the communication subsystem.

Details of the Westar I through III satellites are given in Table 7-7. The first Westar was launched in April 1974 and the second in October 1974. Regular service began in July 1974 with five Western Union terminals in major urban areas of CONUS. Westar III was launched in August 1979. Westar I was removed from service in April 1983. The other two satellites are in use.

Advanced Westar, proposed as the second generation space segment, and the NASA TDRSS space segment (Section 7.4) are integrated into a common satellite design. The basic design is described in the TDRSS discussion. The satellite has three communication subsystems: S-band for TDRSS, C-band for Advanced Westar, and K-band for either system. However, conflicts developed which led to termination of the joint Western Union and NASA use of the satellites. The satellites will be used only by NASA, even though they still have the Advanced Westar equipment.

In 1980, Western Union ordered a Westar IV satellite, primarily to ensure no gap before Advanced Westar was available. Westar V and VI were added within a year. With the end of Advanced Westar, the company applied for permission to build Westar VII and VIII. Table 7-8 summarizes the details of the Westar IV through VIII satellites.

The Westar IV through VIII are larger and have more capacity than the earlier satellites. Except for communication subsystem details, the satellites are the same as the SBS satellites. They have a cylindrical body, which is covered with solar cells except for a band that is a thermal radiator. Additional power is generated by a cylindrical array that surrounds the main body during launch and is deployed in orbit. The antenna, which is deployed in orbit, and the communications equipment are mounted on a platform that is despun during satellite operations. The satellite is shown in Figure 7-11 with antenna and solar array deployed.

The communication subsystem has 24 channels, and transmits and receives 12 on each of two orthogonal linear polarizations. Signals received on one polarization are transmitted on the opposite one. The dual polarized main beam covers CONUS, Alaska and the Carribbean, with lesser gain for the latter two. A secondary beam covers Hawaii with only one polarization in satellites IV and V, but both in satellite VI. Internally the subsystem (Figure 7-12) is typical of many other satellites with broadband receivers and individual TWTs for each channel.

Westars IV and V were launched in 1982 and are in use. Westar VI was launched in February 1984 but was left in a low orbit because of a perigee motor failure. Westar VII and VIII are scheduled for launch in fall 1985 and fall 1986, respectively.

The proposed Westar IX to XI satellites will operate in the 12- and 14-GHz bands. The communication subsystem is planned to have 16 channels with 54 MHz bandwidths, and use dual polarizations. This basic design is identical to the communication subsystem of Anik C. The satellite design is not fixed yet. It will probably be similar either to the Westar IV type or the RCA type. Launches are desired in 1985 and 1986; more likely the first will be in 1986.

The Westar satellite control center is at a Western Union ground terminal in New Jersey. Western Union has ground terminals near six other major urban areas. These are used for transmission of telephone and message traffic. Several other companies have their own ground terminals that they use with the Westars for telephone, data, and video conferencing. The largest network of this type is American Satellite Company (see Section 7.2.9). The biggest use of Westar satellites is for distribution of TV programs. The Public Broadcasting System uses Westar to distribute four programs to almost 200 ground terminals associated with its member stations. Numerous companies use Westar to distribute regular programming or occasional events to cable TV systems. The number of ground terminals receiving such programs is continually growing and probably is 1000 or more. Other uses of Westar include transmission of facsimile pages of The Wall Street Journal to more than a dozen printing plants around the nation.

7.2.3 AT&T (Comstar, Telstar 3) (Refs. 407-423)

The AT&T system began operating in 1976 using the Comstar satellites (Figure 7-13 and Table 7-9). They are a derivative of Intelsat IV. The two satellites are the same size, and the structure and support subsystems are very similar. Like Intelsat IV, Comstar is a dual-spin type satellite. Externally, the body is a cylinder covered with solar cells. Internally, most support equipment is attached to the spinning structure. The communication subsystem and antennas are mounted on a despun shelf, which is oriented to keep the antennas earth pointing. Although the solar array is the same size as that of Intelsat IV, the end of life power is greater due to the use of newer, higher efficiency solar cells.

The communications subsystem (Figure 7-14) is a new design relative to Intelsat IV and has 24 channels. Twelve channels plus the guardbands between them they almost fill the 500-MHz band, so the band is "reused" by receiving and transmitting 12 channels with horizontal polarization and 12 channels with vertical polarization. Within the satellite, each of these 12-channel groups uses a different receiver; every channel has its own TWT.

Separate antennas for each polarization provide coverage of CONUS, while one has additional feed horns for coverage of Alaska and the other for Hawaii and Puerto Rico. Six channels are permanently connected for CONUS coverage. The output of each of the other six channel groups is switchable between one of the outlying areas and CONUS.

In addition to the communication subsystem, the satellites also have beacon transmitters at 19.04 and 28.56 GHz for use in propagation measurements. The data collected in these experiments will be useful in the design of a later generation of satellites that will use the 18- and 30-GHz bands.

Comsat General Corporation developed these satellites and operates them under a lease agreement with AT&T. The first two satellites were launched in 1976, the third in 1978, and the fourth in 1981. After the fourth launch, the two older satellites were collocated to be operated as a single satellite. Each provides half of the 24 repeaters. All of the Comstars were in use as of mid 1983.

The second generation of satellites in the AT&T system are called Telstar 3 (Figure 7-15). They are being obtained directly by AT&T rather than through the lease arrangement used for the Comstars. The Telstar satellites have the same configuration as Anik C and SBS. The basic external features in the left side of Figure 7-15 are the 6-foot antenna, the main body, which contains all the equipment and the lower, deployable, solar array. The clear band in the middle of the main body solar array is a thermal radiator, which is closely coupled to the power amplifiers of the communication subsystem.

The communication subsystem (Figure 7-16) is functionally the same as that of the Comstar satellites. It has 24 channels using dual polarization transmission and reception. Of the 24, six are always connected to the CONUS transmit beam, and the other sets of six are switchable between the beams for CONUS and other areas. Internally, there are two main changes from the Comstar communication subsystem. One is the addition of the six spare amplifier chains. The other is the use of solid state amplifiers. Eighteen

of the 30 power amplifiers are constructed with field effect transistors - a single first stage followed by three successive stages, each with two parallel transistors. The other 12 amplifiers are TWTs.

Development of the Telstar 3 satellites began in 1980. The first was launched in July 1983. The other two launches are scheduled for 1984 and 1985. Gradually traffic will be transferred from the Comstars to the Telstars.

The Telstar 3 satellites are being operated by AT&T. Satellite control equipment has been added to an existing AT&T ground terminal in Pennsylvania. Equipment was also added to an existing terminal in California as a backup to the primary site. Eight other communication terminals, not all operated by AT&T, comprise the basic network. Links between these terminals are either part of the public telephone network or the private telephone network operated by AT&T for the government. Use of the Comstar satellites was restricted to these two applications during the 1976 and 1979 period. The purpose of this restriction, imposed by the FCC, was to allow other domestic satellite companies a chance to establish themselves before facing direct competition from AT&T.

Since 1979, AT&T has been free to use their satellites for any type of communications. Long distance, high capacity voice links are still a major source of traffic, but television distribution is increasing. The TV services include both regular network TV and occasional uses. Other traffic includes high speed data and video conferencing.

7.2.4 RCA (Refs. 424-446)

The RCA satellite has a boxlike body. Solar panels are deployed in orbit from two opposing sides of the body. The antennas are mounted on another side of the body. The satellite body is stabilized to keep the antennas earth oriented, and the solar arrays are rotated about their long axis to track the sun.

The satellites have gradually grown in capability through three stages. All satellites have had the same basic characteristics, but the body size has grown from about 4 x 4 x 5 ft to about 5 x 5 x 6 ft. Also, the early satellites (Figure 7-17) had two sections in each of the two solar panels, whereas the newer satellites (Figure 7-18) have three sections in each panel. The increased solar array size, along with increased solar cell efficiency, allows the array to support a higher power payload for a longer lifetime. Details of the satellites are given in Table 7-11.

The RCA satellite communication subsystem (Figure 7-19) is similar to that of the AT&T satellite in that is has 24 channels with frequency reuse by orthogonal linear polarizations. Like the AT&T satellite, the two polarization groups use separate receivers. The satellite has separate antennas for the two polarizations. The antennas are physically overlapping but each responds to only one polarization because of embedded polarizing grids. On satellites 1 through 4 the main beam of each antenna has a single elliptical footprint that covers CONUS and Alaska (and the intervening part of Canada). An additional offset feed horn provides a separate beam for coverage of Hawaii. Beginning with satellite 5 a different feed structure is used, allowing coverage of these two areas and of CONUS alone or Alaska alone. Switching between different coverage patterns is possible. The first satellites used one TWT per repeater with no redundancy. The next set had one spare TWT for each six repeaters, to improve the reliability. On the newest satellites solid state (FET) amplifiers have replaced the TWTs, again with one for six redundancy. These amplifiers have better linearity than TWTs, affording up to 50 percent capacity increase in multiple carrier per repeater operation.

The first RCA satellites were the first to use the Delta launch vehicle Model 3914. This version of the Delta was developed to meet RCA requirements and was partially funded by RCA, marking the first time a launch vehicle development was privately sponsored. The first launch occurred in December 1975, and the second in March 1976. A third launch in 1979 was unsuccessful. Apparently the satellite was destroyed during apogee motor

firing. Since then there have been five successful launches, one in 1981 and two each in 1982 and 1983.

There are currently seven RCA satellites in orbit. The two launched in 1983 are gradually replacing the first two. One of the five active satellites (number 5) was sold, prior to launch, to Alascom Inc. Alascom was formerly a RCA subsidiary, but is now owned by Pacific Power and Light Co. It has the responsibility to provide long distance communications within Alaska and between Alaska and other states. The other four satellites are part of the basic RCA network.

RCA takes care of satellite command and telemetry for both its own satellites and the Alascom satellite. The primary control site is integrated with a communications terminal in New Jersey. A secondary control site is integrated with another communications terminal in Southern California. RCA has five other major communications terminals for commercial traffic of all types. RCA also owns about 25 terminals in its government services network.

The commercial terminals handle primarily voice and data traffic. The government services network is all data with link rates varying from 56 kbps to 50 Mbps. The primary customer is NASA. There are also 135 to 140 terminals in Alaska, mostly 15-ft diameter, although about thirty are 33-ft diameter or larger. They are used for telephony, and for distribution of radio and television programs. Many of these terminals serve multiple villages in a small area via terrestrial RF links.

In spite of all the above uses, the biggest use of the RCA satellites is for distribution of television programming. Two satellites are wholly assigned to this and several channels on other satellites are also used. While the number of ground terminals able to transmit to the satellites is in the dozens, the number of receive only terminals is in the thousands and is growing by as much as 1000 per year.

In 1985 or later RCA will launch additional satellites to replace some of those currently in operation. RCA also has approval to operate a K-band (12/14 GHz) system in addition to the current C-band (4/6 GHz) system. The satellites will have 16 repeaters, and will resemble the GStar satellites being built by RCA. The emphasis is high power satellites for service to small ground terminals primarily in the CONUS. Service to Alaska and Hawaii would continue on the current system. The first launch will take place in the second half of 1985 or in 1986.

7.2.5 Satellite Business Systems (Refs. 447-460)

The SBS satellite (Figure 7-20) is very similar in design to the Anik C satellite. During launch it is a compact cylinder. In orbit, the antenna unfolds from one end of the satellite and a cylindrical solar array is deployed axially at the other end. When the solar array is deployed it reveals the main cylindrical body of the satellite, which is also covered with solar cells except for a mirrored band that serves as a thermal radiator. Design details for the satellite are summarized in Table 7-12.

The communication subsystem (Figure 7-21) is relatively simple. It has ten channels that use a common broadband receiver and individual transmitters. There are 16 transmitter sections, each consisting of a low level amplifier and a 20-W TWT connected through switching networks to provide six spares for the ten channels. The antenna is hinged for deployment and for north-south pointing. East-west pointing is accomplished by adjusting the pointing of the despun communications equipment shelf on which the antenna is mounted. Pointing control is derived from signals produced by a four-horn monopulse network integrated with the regular receive horns. The receiving and transmitting antenna feeds are separate multihorn arrays, which provide a weighted beam that is strongest in the eastern part of the country (Figure 7-22 and Table 7-13).

SBS ordered three satellites at the end of 1977. The first was launched late in 1980 and the second in 1981. The third was launched in November 1982 on the first STS flight to deploy commercial payloads. All three satellites are operational. At the beginning of 1982 SBS ordered a fourth satellite, which is scheduled to be launched in the fall of 1984. In 1983 modifications of this satellite were begun to improve its usefulness to Satellite Television Corporation (see Section 7.5).

The SBS network was designed to provide integrated voice and data services primarily to large corporations that have facilities at several sites in the United States. The SBS design was unique in serving only CONUS, and in using digital, demand-assigned, TDMA links for all transmissions. The system as operated today largely follows this plan, with corporate customers served via either on-site, dedicated terminals or sharing a terminal with several customers in a local area.

The services provided to the majority of customers are dedicated digital networks connecting two or more sites. The capacity of the links can be allocated by equipment at the sites among various uses including voice circuits, video conferencing, and data and fascimile transmissions. For multisite customers, their total network capacity can be allocated among the various possible links to meet changing needs on a daily or long term basis. SBS also provides general purpose long distance communications between a number of their own terminals for customers who are too small to justify the equipment necessary for a dedicated network. Other uses of the satellites include a small amount of broadcast television distribution and some occasional-use video conferencing.

The SBS ground terminals include an antenna, an exterior equipment shelter, and some equipment inside a customer's building. Most antennas are about 18 ft in diameter. Some, for use in regions of very high rainfall or lower satellite performance are about 24 ft in diameter. SBS ordered 200 terminals, half from each of two manufacturers. It is installing them as required to serve its customers.

The SBS satellites are controlled from TT&C sites at Castle Rock, Colorado and Clarksburg, Maryland. Both sites have the same TT&C equipment, but the system data processing and control center is the Maryland site. The Colorado site is the primary beacon transmitter. The satellites use the received beacon for antenna pointing control.

7.2.6 Hughes Communications (Galaxy) (Ref. 461)

Hughes Communications Inc. (HCI) is a subsidiary of Hughes Aircraft Company. The HCI Galaxy satellites are almost identical to the Westar IV through VIII satellites (Figure 7-11) and the Telstar 3 satellites (Figure 7-15). All these satellites have the same body with the cylindrical, deployable solar array and the mirrored thermal radiator band. Also, all have a deployable antenna, attached to a despun communications equipment platform on the end opposite the deployable solar array. The satellite diameter is about seven feet. Its height is only nine feet in the stowed, launch configuration, but over 22 feet when deployed. Other details concerning the Galaxy satellites are provided in Table 7-14.

The Galaxy communication subsystem operates in the 4- and 6-GHz bands. It has the currently common arrangement of 24 channels, with 12 on each of two orthogonal polarizations. There are four wideband receivers, one for each polarization and two spares. The output sections are one per channel, with one spare for every four channels. These characteristics are shown in Figure 7-23.

The first Galaxy satellite was launched in June 1983. Its assigned location provides visibility to all 50 states and Puerto Rico. In 1981 HCI began to sell channels on this satellite to distributors of TV programming. The sales gave the distributors control over their own satellite resources. In turn, the use of one satellite by so many distributors was an inducement to many cable TV system operators to install an antenna to receive the programming available on Galaxy 1. Currently 19 or 20 channels are in use with the others as reserves but available for occasional, preemptible uses.

Galaxy 2, launched in September 1983, and Galaxy 3, to be launched in 1984, are located farther east and have poor visibility from Alaska and Hawaii. They will be used primarily for business communications in CONUS, including telephone, data and video conferencing applications.

The Galaxy satellites are operated from a control center in the HCI facility in Los Angeles. The primary TT&C site is located near New York City. Another site is in Ventura County, about 50 miles north of Los Angeles.

In spring 1983 HCI applied for permission to operate a set of 12- and 14-CHz satellites in addition to the current Galaxy satellites. These satellites are proposed to have 16 channels each, probably similar to Anik C, but with very high power TWT amplifiers. The satellite body is planned to be similar to Intelsat VI, much larger than the current Galaxy design. Two launches are scheduled for late 1985 and 1986, with a third later. However, the launch schedule depends strongly on when the FCC grants approval of the system. Even if approved soon, it is unlikely that operations would begin before 1987.

7.2.7 Spacenet (Refs 462-463)

Southern Pacific Communications Company (SPCC) has, for many years, operated a network for dedicated and public long distance telephone and data links. SPCC owned much of the terrestrial portion of the network, but has leased all the satellite portion. The leased satellite capacity will be replaced by the Spacenet satellites beginning in 1984.

The Spacenet design is based on the RCA satellite design, and is very similar in appearance. Figure 7-24 shows the satellite in deployed condition. The central body is approximately a cube. The two sun-tracking solar array wings are each composed of three panels, which are folded against the satellite body for launch. The antenna feed horns and reflectors are mounted on the earth-viewing side of the satellite body. The two spheres protruding from one side and the opposite side, are tanks for propellant used

for attitude adjustments and stationkeeping maneuvers. Satellite details are provided in Table 7-15.

Spacenet will be the first U.S. domestic satellite that operates in both the 4/6-GHz and the 12/14-GHz frequency bands. The satellites currently in orbit all operate in either one or the other of these two bands. The primary objective in the communication subsystem design was to maximize bandwidth subject to launch vehicle imposed weight constraints. The result is a 24-channel design with 50 percent more bandwidth than existing 24-channel 4/6-GHz designs.

The 4/6-GHz portion of the communication subsystem (Figure 7-25) has two sections. One is a typical set of twelve 36-MHz bandwidth repeaters. The other section, using the orthogonal antenna polarization, has six 72-MHz bandwidth repeaters. The weight saved, relative to a twelve-repeater design, allows an additional six repeaters of 72 MHz bandwidth. These six operate in the 12/14-GHz band (Figure 7-26). The narrowband (36 MHz) repeaters use the same solid state amplifiers that the new RCA satellites use. The wideband repeaters use TWTs with twice the output power. The 4/6-GHz antenna patterns are adjusted to the expected satellite location. The western satellite pattern includes all 50 states plus Puerto Rico, whereas the eastern satellite pattern emphasizes CONUS and the Carribbean, because of limited visibility from Alaska and Hawaii. The 12/14-GHz pattern is optimized for CONUS coverage, with some degradation in parts of Texas, Florida, and Maine.

Two Spacenets are scheduled for launch in 1984. The first will be stationed in a westerly location and the 4/6-GHz channels will mostly be used for distribution of television programs. The second satellite, and the third, expected to be launched in 1985, will primarily be devoted to business communications. Types of traffic will include voice, data, facsimile, and video conferencing. Half of the capacity of the second and third satellites has been sold to MCI, which (like SPCC) has already been operating a long distance communications network based on its own terrestrial facilities.

The control center for the Spacenet satellites is in Virginia, near Washington D.C. The primary TT&C site is located in a suburban area of Maryland.

In October 1982, GTE and Southern Pacific agreed that GTE would acquire all the stock of SPCC. Other communications companies objected to the agreement because of the size of the combination, both in terrestrial and satellite communications. However, the agreement was completed by September 1983 and the system is now called GTE Spacenet.

7.2.8 GTE Satellite (GStar) (Refs. 464-467)

GTE Satellite Corporation (GSat) is the owner of the GStar spacecraft which are in development. Like the Spacenet satellites, the GStars have a design based on the RCA satellites. The GStars (Figure 7-27) have a central box-like body structure from which the two sun-tracking solar arrays are deployed. The antenna structure is fixed on the earth-viewing side of the body. All other equipment is mounted within or on the surface of the body. The satellite has nickel-hydrogen batteries and electrothermal hydrazine thrusters, both of which are new technology items, not yet common in communication satellites. Both contribute to increased life for a given satellite weight.

The GStar communication subsystem uses the 12- and 14-GHz bands. The subsystem (Figure 7-28) has sixteen channels, each with a 54-MHz bandwidth, and employs dual polarization frequency reuse. The receive antenna provides CONUS coverage on one polarization and a "combined" coverage for CONUS, Alaska, and Hawaii on the other. The transmit antenna has four beams. Channels 1 and 3 are permanently connected to a combined coverage beam. Each of the other 14 channels has a variable power divider. These dividers can route the power to either a west beam or an east beam or split the power between the two to form a CONUS beam. The west and east coverages correspond to the parts of CONUS west and east of the Mississippi River. Figure 7-29 shows these coverage areas.

Channels 1 and 3 have 30-W TWTs, and all other channels have 20-W TWTs. The power radiated by the satellite is sufficient to support 60 Mbps transmissions in the CONUS and combined beams, or 90 Mbps in the west and east beams. A total of 20 TWTs are available in a ring redundancy arrangement, three of which are the 30-W type. The GStar receivers have a parametric amplifier for the first stage and a FET amplifier second stage, followed by downconversion and additional amplification. Performance values and other satellite details are provided in Table 7-16.

The first two GStar launches are scheduled in mid and late 1984. Two additional launches are scheduled in 1985 and 1987. The primary traffic on all the satellites is expected to be customized digital networks. Each network will serve a specific user; in most cases the ground terminal will be located at the user's facilities. The transmissions will be in a TDMA mode at either 60 or 90 Mbps. Each network can have demand assignment equipment to increase efficiency. The type of information to be transmitted is not constrained. User equipment can combine voice, data, facsimile, and video inputs to form the transmitted data stream.

Typical ground terminals for the 60 Mbps networks will have 18- to 25-ft diameter antennas and 500-W output power. For the 90 Mbps networks the antenna diameter will be 25 to 30 ft and the power 1000 W. Specific antenna sizes will depend on the location because rain attenuation and satellite performance vary with location. Active uplink power control may be used in locations with high rain attenuation.

The GStar satellite control facility is located at the GSat corporate site in Stamford, Connecticut. The primary TT&C site will be located a short distance away and the alternate TT&C site will be in Colorado.

7.2.9 American Satellite Corporation (Refs. 468-476)

American Satellite Corporation (ASC)* began providing communications services in 1974, using satellite capacity leased from Western Union. In 1980 ASC converted its lease to a 20 percent ownership of the Western Union satellites. To allow for further growth, in March 1983 ASC signed a contract for the development of its own satellites.

The ASC satellite, a derivative of the RCA satellite, is almost identical to the Spacenet satellite (Figure 7-24). It is a body-stabilized type, having a box-shaped body with solar arrays deployed from the north and south sides of the body. The communications antennas are fixed on the earth-facing side of the body.

One unique feature is that the satellite is the first commercial satellite to have an encrypted command link. The satellite also uses the relatively new nickel-hydrogen battery and electrothermal thruster technologies. The communications subsystem, like Spacenet, has 24 channels. Twelve are 36-MHz bandwidth, sharing the lower half of the 4- and 6-GHz bands by means of dual polarization frequency reuse. The upper half of the same bands are used by six 72-MHz bandwidth channels also by means of dual polarization. In the 12- and 14-GHz bands six 72-MHz bandwidth channels use a single polarization. (Launch weight limits preclude additional channels on the orthogonal polarization). The 36-MHz channels use transistor power amplifiers; the others use TWTs. The subsystem configuration is shown by the Spacenet block diagrams (Figures 7-25 and 7-26). Additional details are provided in Table 7-17.

*From 1973 to 1979 ASC was a subsidiary of Fairchild Industries. Since 1979 it has been a joint venture of Fairchild and Continental Telephone.

The ASC ground terminals are grouped by the services they support: public commercial, dedicated commercial, and dedicated government. In 1974 ASC began with three public and three government terminals. At the end of 1978 23 terminals were in operation. By 1983 the number grew to about 130 terminals. The public terminals have 33-ft antennas. Dedicated commercial terminal antenna sizes vary from 10 to 33 ft, with 16 ft and 23 ft being the most common. Error correction coding is used on most links, and encryption is an option used on some links.

Currently 10 terminals in major urban areas provide the public commercial service. Numerous corporations lease capacity for one to several dozen voice circuits and/or for data circuits at rates up to 56 kbps. The users are linked to ASC central offices via telephone company lines. The central office is linked to the terminal by microwave transmissions, and the terminals communicate with each other via a 64-Mbps TDMA network.

Dedicated commercial terminals are located at customer sites to provide private communication networks. Over 70 terminals are in use. Types of information transmitted on these networks include voice, single and multiple data links at 9.6 or 56 kbps, facsimile, and video conferencing. Transmissions are all digital, with either FDMA single channel per carrier (SCPC), or TDMA operation.

Approximately 50 dedicated government terminals serve NASA, DoD, and the Department of Energy. Transmissions are digital with bit rates ranging from 56 kbps to 3 Mbps. Examples of traffic include data for the Shuttle and Defense Meteorological Satellite programs and 24 voice circuit trunks.

7.2.10 Other Systems

United States Satellite Services, Advanced Business Communications, and Rainbow Satellite have received system approval from the FCC. However, each has to supply further proof of their ability to the FCC. It seems unlikely that all these companies, if any, will begin operations by 1986.

Each of the three has announced plans for satellites using the 12- and 14-GHz bands. Since none of them have discussed satellite details publicly, no specific data can be provided.

Several other applications are pending before the FCC. Two are from RCA and HCI, regarding 12/14-GHz satellites that they wish to develop to complement their existing 4/6-GHz satellites. Ford Aerospace Satellite Services Corporation, a subsidiary of Ford Aerospace and Communications, is a new applicant. Their proposed satellites are called Fordsat.

The Fordsat is a derivative of the Intelsat V and V-A. Figure 7-30 is a drawing of the satellite. The Fordsat weight is more than twice that of any other current U.S. domestic satellite. Its total channel capacity is 50 percent greater than Spacenet and the ASC satellites, which have the next largest capacity. Table 7-18 lists the proposed characteristics of the satellite.

Table 7-6. Domestic Communication Satellite Summary

Organization	Frequency Band	a	b	c	d
Western Union	4/6	3	2		4
	Both		2	4	
RCA	4/6	2	6	4	5
	12/14				3
AT&T	4/6	3	4	3	4
SBS	12/14	1	3	2	5
Hughes Communications (HCI)	4/6		3	2	3
Southern Pacific (SPCC)	Both		3	2	3
GTE Satellite (GSat)	12/14		3	2	2
American Satellite (ASC)	Both				2
United States Satellite Services	12/14				2
Advanced Business Communications	12/14				2
Rainbow Satellite	12/14				2

[a]Number of satellites in orbit at end of 1980.
[b]Number of ground spares, in construction, or construction authorized by the end of 1980.
[c]Number of orbital locations authorized at end of 1980.
[d]Number of orbital locations authorized at mid 1983.

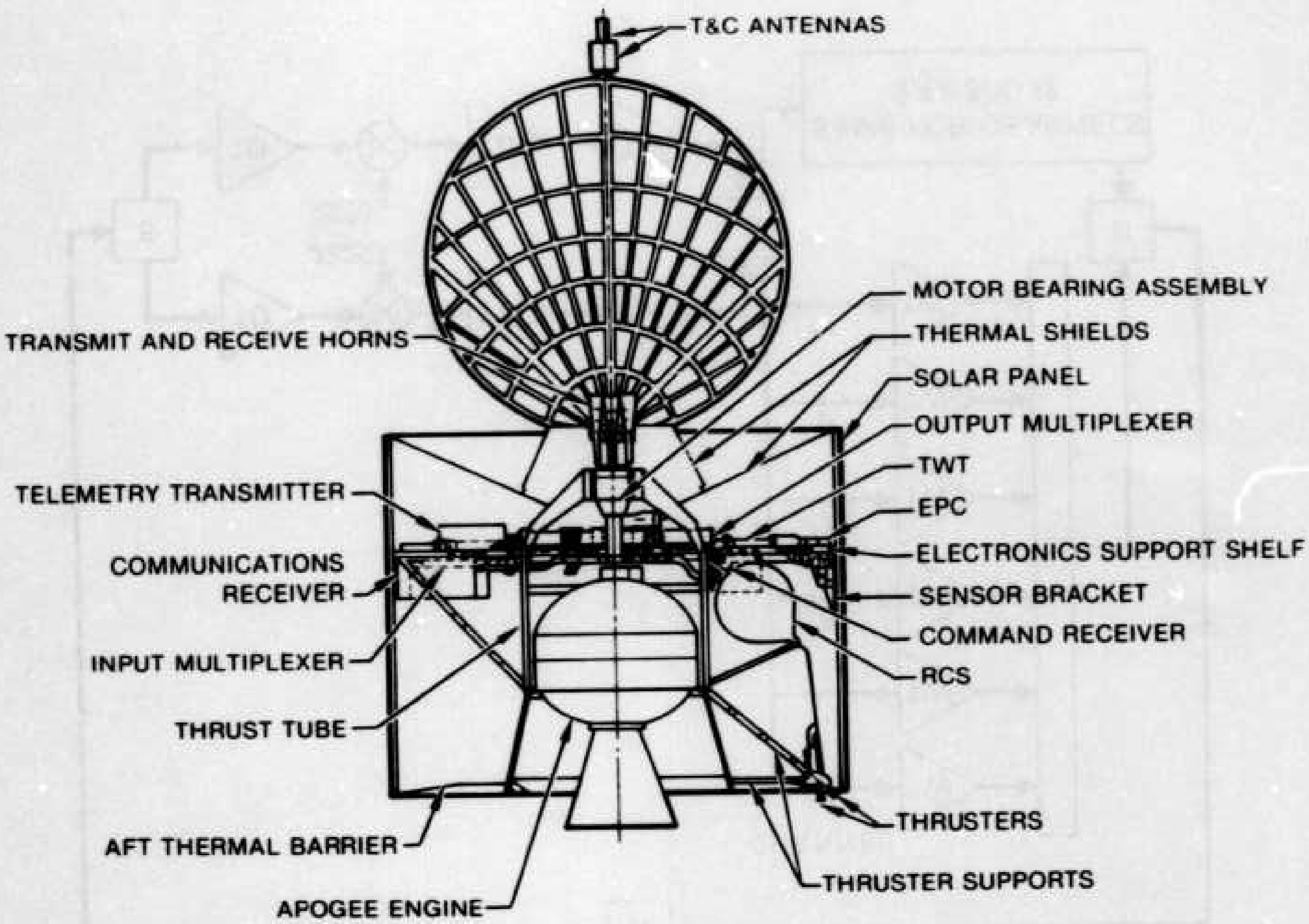


Figure 7-9. Westar I through III Satellite

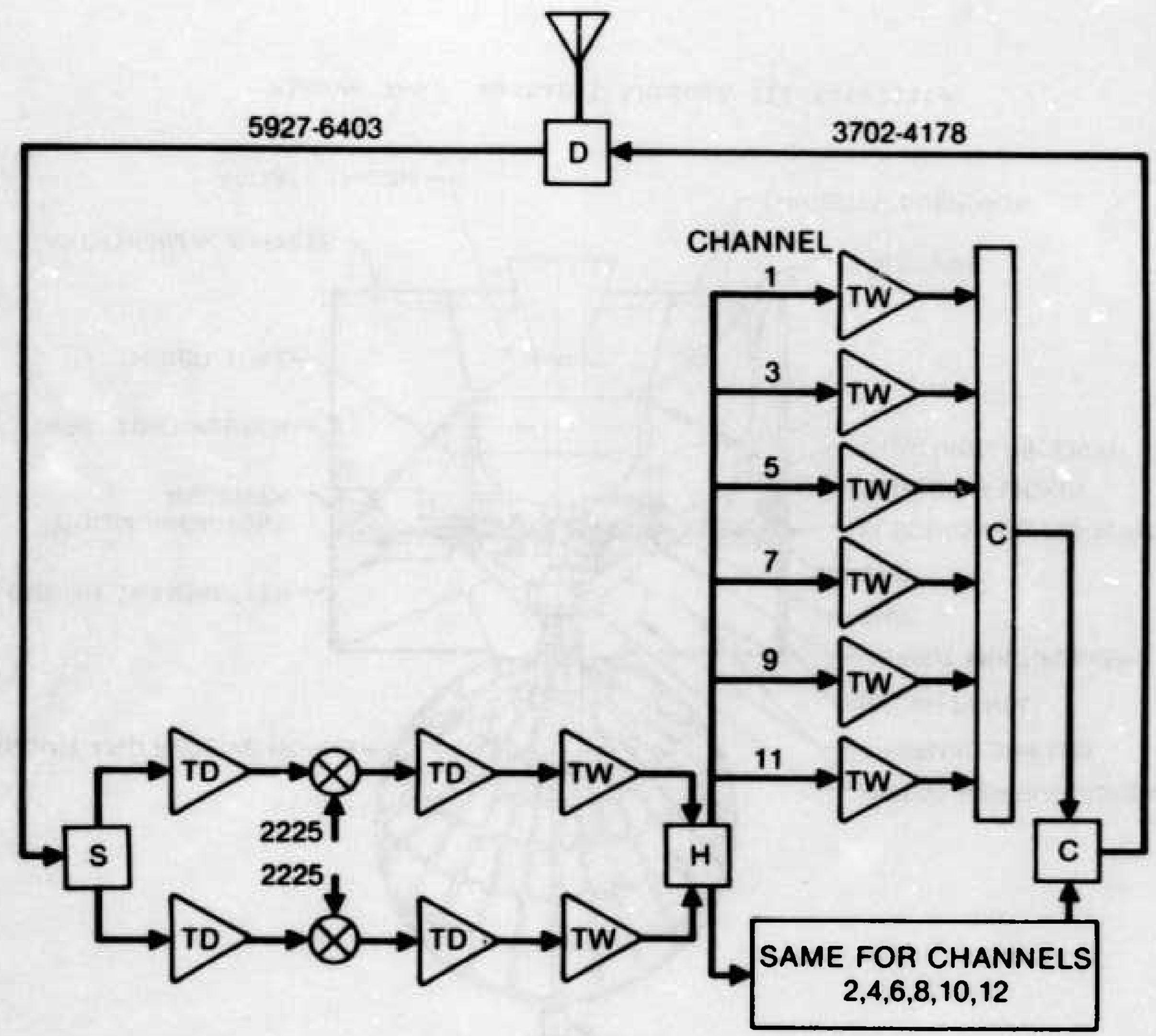


Figure 7-10. Westar I through III Communication Subsystem

Table 7-7. Westar I through III Details

Satellite	Cylinder, 75-in. diameter, 67 in. high, overall height 139 in. 655 lb in orbit, beginning of life Solar cells and NiCd batteries, 305 W at beginning of life, 260 W minimum after 7 yr Spin-stabilized, 100 rpm, $\pm 0.1^{\circ}$ accuracy
Configuration	Twelve 36-MHz bandwidth single conversion repeaters
Capacity	Up to 1200 one-way voice circuits or 1 TV program per repeater
Transmitter	3702 to 4178 MHz One 5-W TWT per repeater (no TWT redundancy) ERP per repeater at edge of coverage: 33 dBW (CONUS), 27 dBW (Puerto Rico), 24.5 dBW (Alaska, Hawaii)
Receiver	5927 to 6403 MHz 2 receivers (1 on, 1 standby), 8-dB noise figure G/T at edge of coverage: -7 dB/$^{\circ}$K (CONUS), -14 dB/$^{\circ}$K (Alaska, Hawaii)
Antenna	One 60-in. diameter reflector with 3 feed horns combined for coverage of CONUS and Puerto Rico separate feed horns for Alaska and Hawaii; linear polarization
Design Life	7 yr
Orbit	Synchronous equatorial, stationkeeping to $\pm 0.1^{\circ}$N-S and E-W
Orbital History	I: Launched 13 Apr 1974, turned off Apr 1983, moved out of geosynchronous orbit II: Launched 10 Oct 1974, 79°W longitude (formerly 90 and 123°W), in use III: Launched 10 Aug 1979, 90°W longitude, in use Delta 2914 launch vehicle
Developed for	Western Union
Developed by	Hughes Aircraft Company
Operated by	Western Union

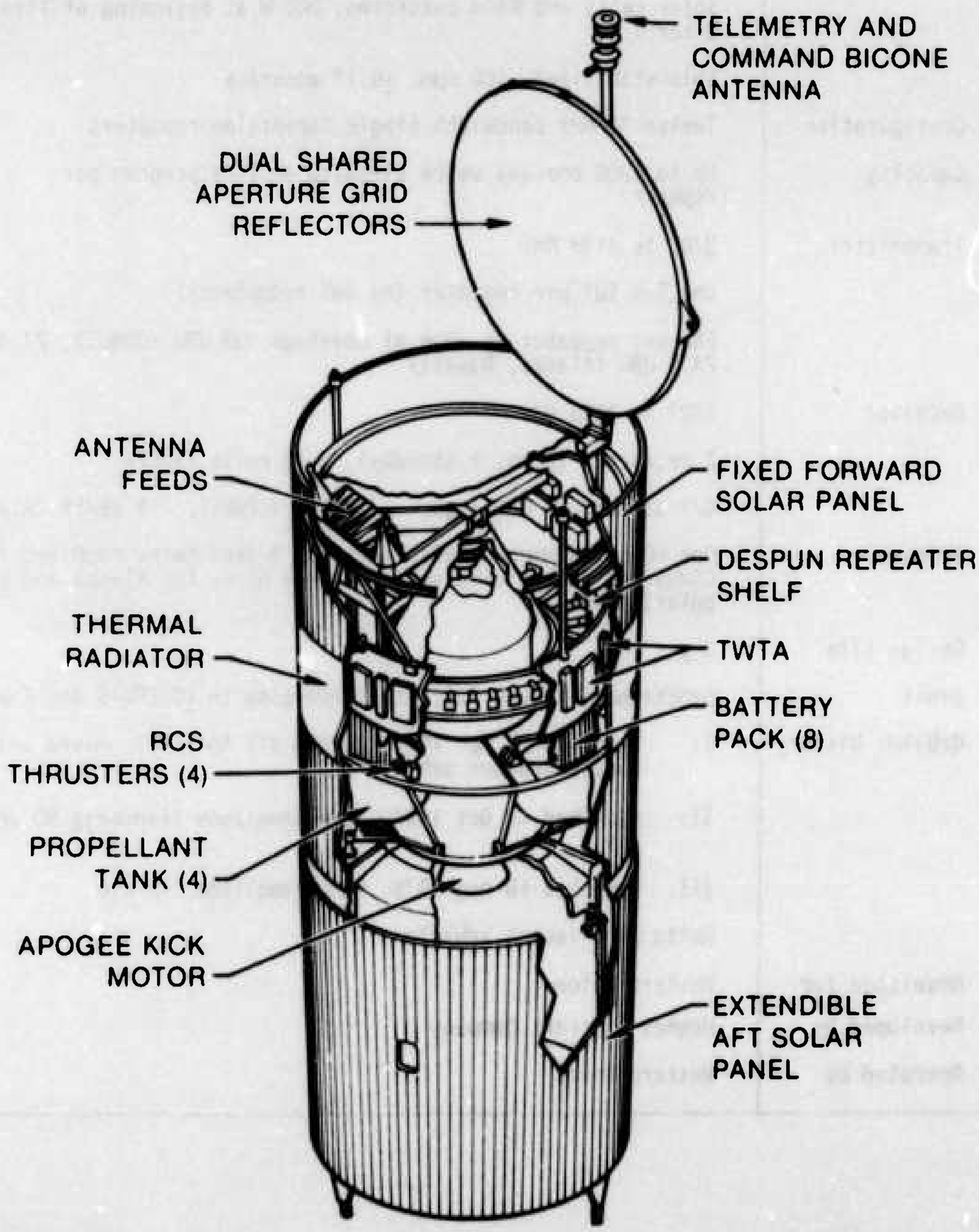


Figure 7-11. Westar IV through VIII Satellite

Table 7-8. Westar IV through VIII Details

Satellite	Cylinder, 85-in. diameter, 269 in. (22.4 ft) tall in deployed condition
	1285 lb[a]/1340 lb[b]/1400 lb[c] in orbit, beginning of life
	Solar cells and NiCd batteries, 840 W[a,b]/960 W[c] at beginning of life, 694 W[a,b]/777 W[c] at end of life
	Spin-stabilized, gyrostat, ~60 rpm
Configuration	Twenty-four 36-MHz bandwidth single conversion repeaters, dual polarization frequency reuse.
Capacity	Up to 1200 one-way voice circuits or 64 Mbps or 1 TV program per repeater
Transmitter	3702 to 4198 MHz
	One TWT per repeater plus 6 spares per satellite; 7.5 W[a]/8.2 W[b]/9.6 W[c] per TWT
	ERP per repeater at edge of coverage: 34 dBW[a]/34.5 dBW[b]/35.2 dBW[c] (CONUS); 31 dBW[a]/31.4 dBW[b]/32.1 dBW[c] (Alaska); 28.3 dBW[a]/28.4 dBW[b]/29.1 dBW[c] (Hawaii); 27.2 dBW[a,b]/27.9 dBW[c] (Puerto Rico)
Receiver	5927 to 6423 MHz
	Two active plus two spare receivers
	G/T at edge of coverage: -4 dB/°K (CONUS), -[illegible].1 dB/°K (Alaska), -10.7 dBW (Hawaii), -9.1 dB/°K (Puerto Rico)
Antenna	Two 72-in. diameter paraboloids with polarizing grids, one behind the other; primary beam shaped to cover CONUS, Alaska, and Puerto Rico; secondary beam to cover Hawaii; orthogonal linear polarizations
Design Life	10 yr
Orbit	Synchronous equatorial, stationkeeping to ±0.1° N-S and E-W
Orbital History	IV: Launched 26 Feb 1982, 99°W longitude, in use
	V: Launched 9 Jun 1982, 123.6°W longitude[d], in use
	VI: Launched 3 Feb 1984, PAM failure
	VII: Launch scheduled Fall 1985
	VIII: Launch scheduled Fall 1986
	Delta 3910/PAM launch vehicle (IV,V), Shuttle/PAM launch vehicle (VI-VIII)
Developed for	Western Union
Developed by	Hughes Aircraft company
Operated by	Western Union

[a]Westar IV-V
[b]Westar VI
[c]Westar VII-VIII
[d]Will move to 119°W in 1984

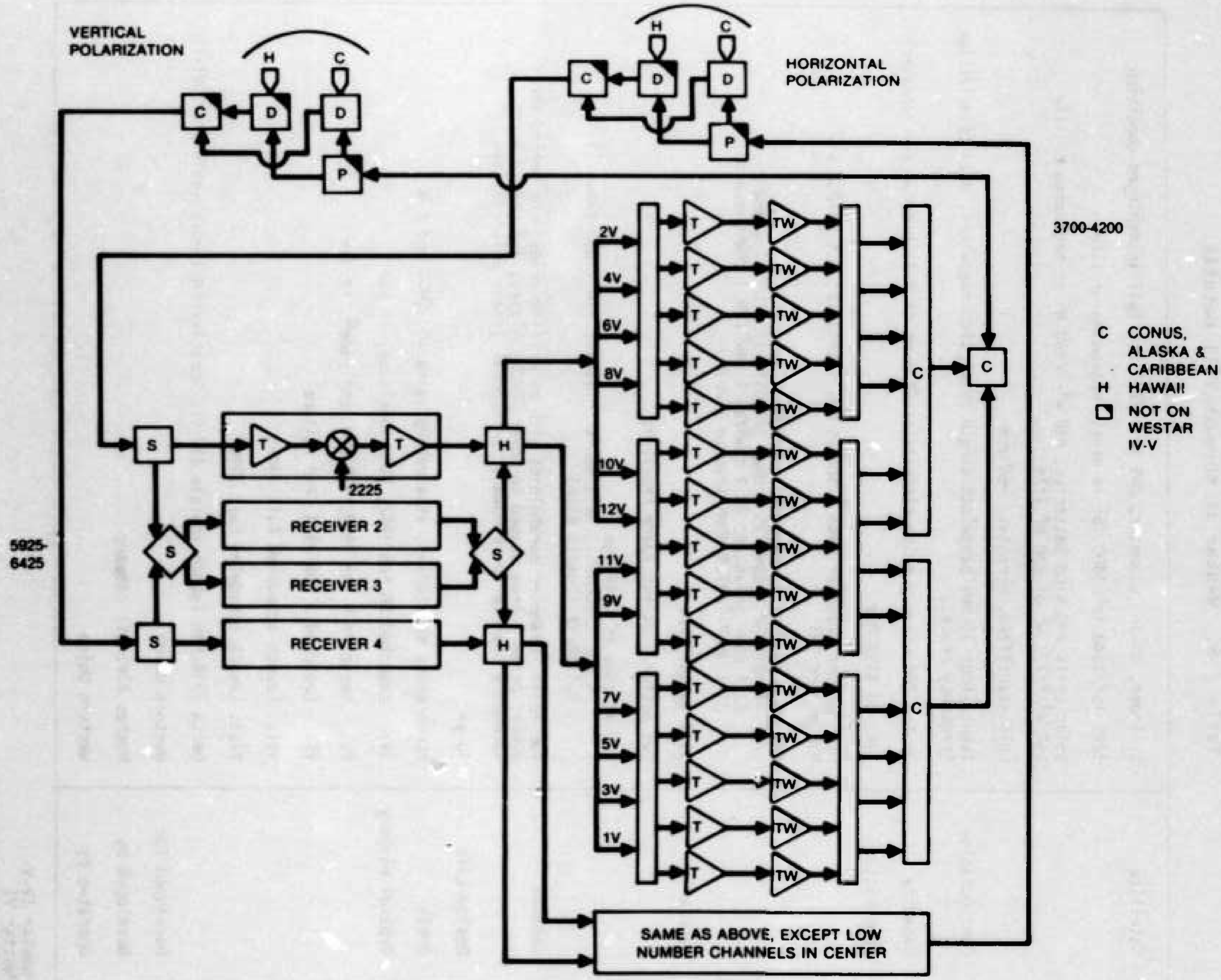


Figure 7-12. Westar IV through VIII Communication Subsystem

Figure 7-13. Comstar Satellite

Table 7-9. Comstar Details

Satellite	Cylinder, 94-in. diameter, 111 in. high, overall height 239 in.
	1787 lb in orbit, beginning of life
	Solar cells and NiCd batteries, 760 W maximum at beginning of life, ~550 W minimum at end of life
	Spin-stabilized, gyrostat, ~55 rpm, maximum antenna pointing error $\pm 0.26^{\circ}$N-S, $\pm 0.2^{\circ}$E-W
Configuration	Twenty-four 34-MHz bandwidth single conversion repeaters, dual polarization frequency reuse
Capacity	Up to 1200 one-way voice circuits or 1 TV program or 45 Mbps per repeater, specified; actual use can be $\geq$1500 one-way voice circuits plus 1.5 Mbps data
Transmitter	3700 to 4200 MHz
	One 5-W TWT per repeater (horizontal polarization transmission), one 5.5-W TWT per repeater (vertical polarization transmission), no redundancy
	ERP per repeater at edge of coverage: 33 dBW (CONUS, Hawaii, Alaska, Puerto Rico), 31 dBW (combined CONUS and Alaska coverage), specified; 36 dBW typical, 34 dBW minimum achieved over CONUS
Receiver	5925 to 6425 MHz
	4 receivers (2 on, 2 standby)
	G/T: -8.8 dB/$^{\circ}$K (specification), -4.5 dB/$^{\circ}$K (typical)
Antenna	2 antennas 50 x 70 in. (1 for horizontal polarization transmission and reception with 6 feed horns to provide CONUS, Hawaii, and Puerto Rico coverage; 1 for vertical polarization with 5 feed horns for CONUS and Alaska coverage); 24.5-dB receive gain, 26.5/27-dB transmit gain (vertical/horizontal); CONUS beam ~$3.5^{\circ} \times 7^{\circ}$
	33-dB isolation between the 2 polarizations
Design Life	7 yr
Orbit	Synchronous equatorial, stationkeeping to $\pm 0.1^{\circ}$N-S and E-W
Orbital History	1: Launched 13 May 1976; 95°W longitude, in use
	2: Launched 22 Jul 1976; 95°W longitude (formerly 128°W), in use
	3: Launched 29 Jun 1978; 87°W longitude, in use
	4: Launched 21 Feb 1979; 127°W longitude, in use
	Atlas-Centaur launch vehicle
Developed for	Comsat General Corporation (for lease to AT&T)
Developed by	Hughes Aircraft Company
Operated by	Comsat General Corporation

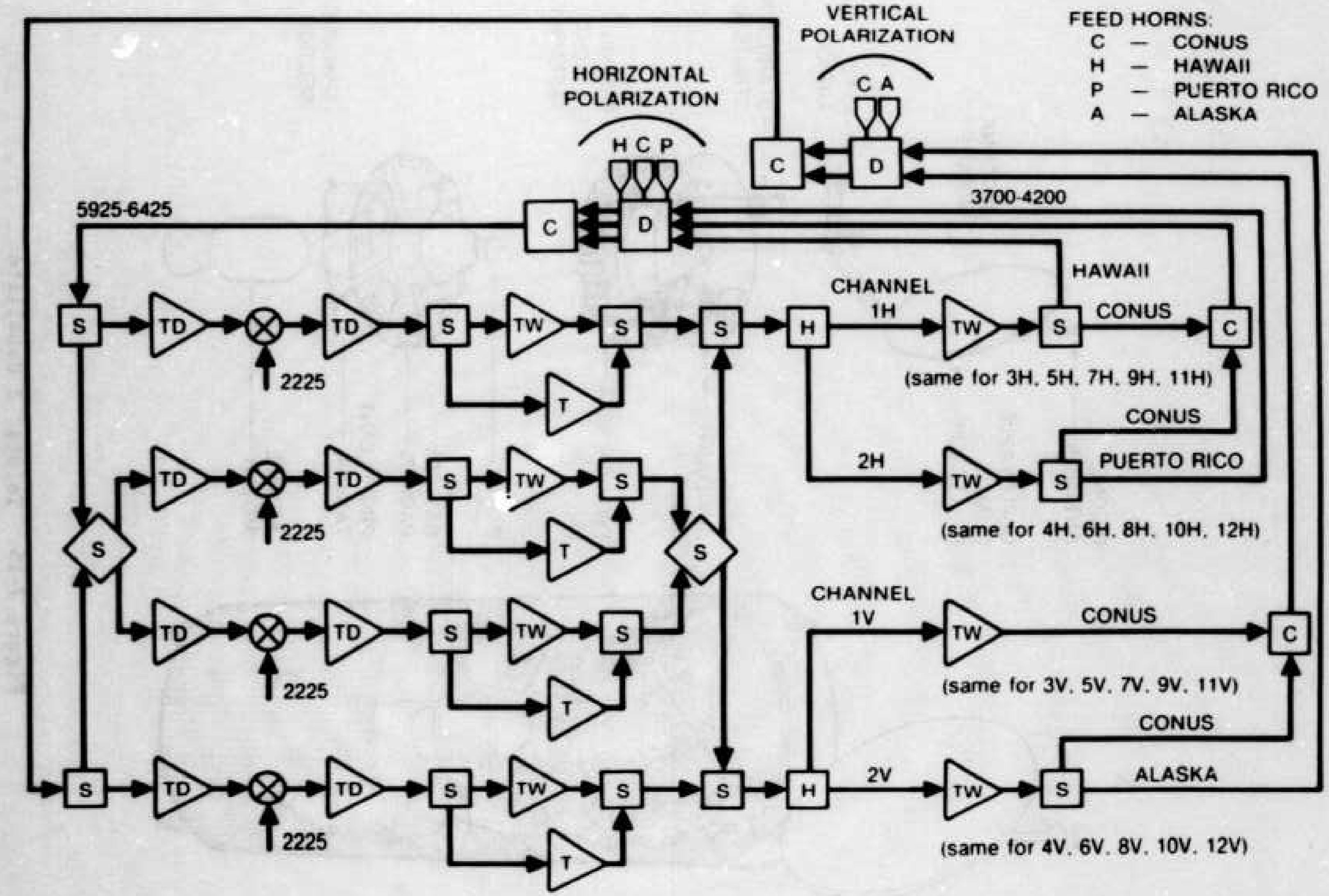


Figure 7-14. Comstar Communication Subsystem

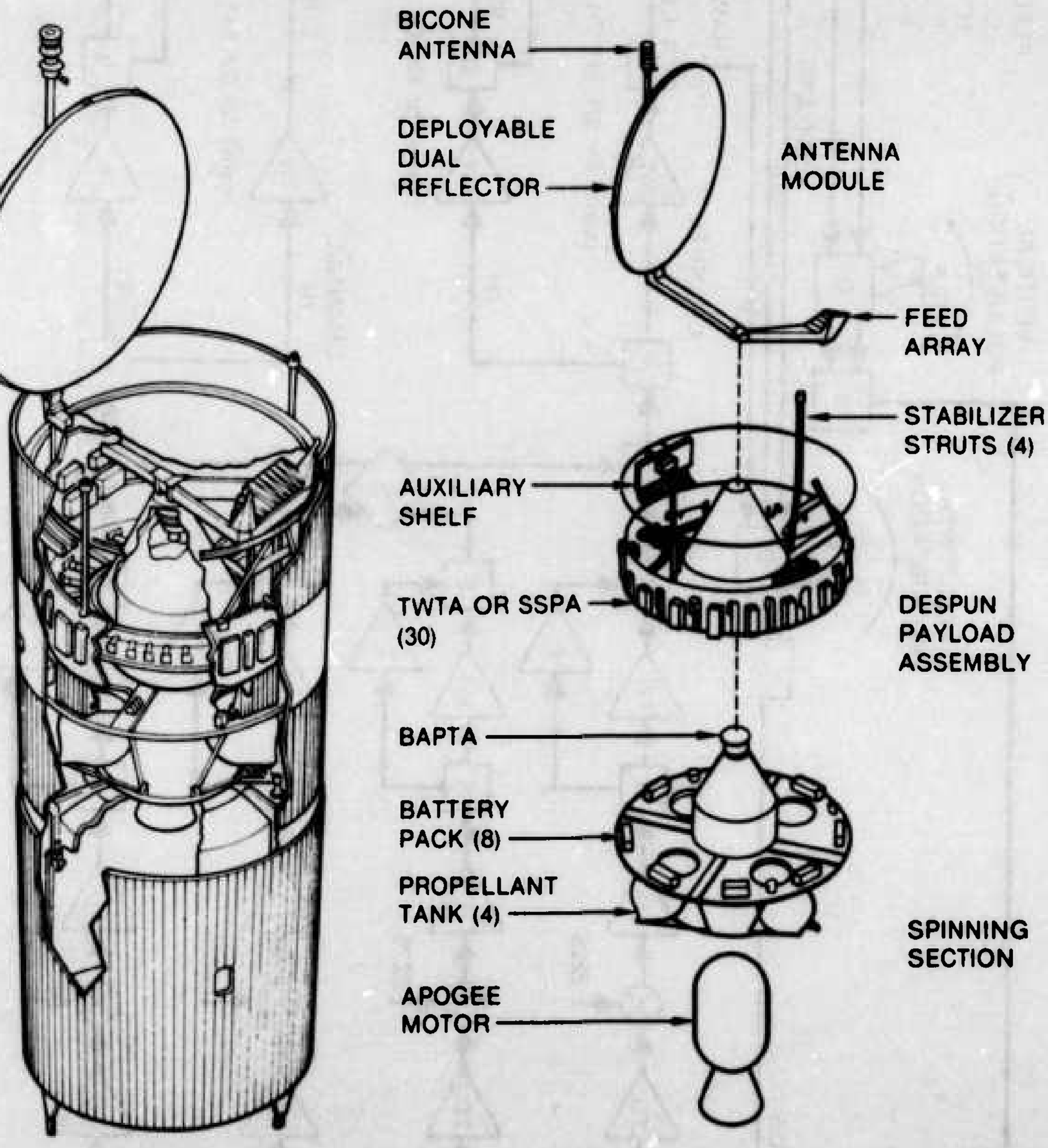


Figure 7-15. Telstar 3 Satellite

Table 7-10. Telstar 3 Details

Satellite	Cylinder, 85-in. diameter, 269 in. (22.4 ft) tall in deployed condition
	1438 lb in orbit, beginning of life
	Solar cells and NiCd batteries, 917 W beginning of life, 670 W end of life
	Spin-stabilized, gyrostat, ~60 rpm, $\pm 0.08^{o}$ antenna pointing accuracy
Configuration	Twenty-four 36-MHz bandwidth single conversion repeaters, dual polarization frequency reuse
Capacity	Up to 7800 one-way voice circuits or one or two TV signals or 30 1.544 Mbps digital signals per repeater
Transmitter	3702 to 4198 MHz
	18 transistorized amplifiers and 12 TWTs in six groups to provide 4 active and 1 spare amplifier for every 4 repeaters; 5.5 W per amplifier
	33 dBW per repeater at edge of coverage
Receiver	5927 to 6423 MHz
	Two active plus two spare receivers
	$\geq$-5 dB/^{o}K G/T at edge of coverage
Antenna	Two 72-in. diameter paraboloids with polarizing grids, one behind the other; vertical polarization has 12 feed horns for CONUS beam and 2 for Alaska; horizontal polarization has 4 feed horns for CONUS beam and 1 each for Hawaii and Puerto Rico
Design Life	10 yr
Orbit	Synchronous equatorial, stationkeeping to $\pm 0.1^{o}$N-S and E-W
Orbital History	301 (3A) launched 28 Jul 1983, 96^{o}W longitude, in use
	302 (3B) launch scheduled Aug 1984, will go to 76^{o}W longitude
	303 (3C) launch scheduled May 1985, will go to 88.5^{o}W longitude
	Delta 3920/PAM launch vehicle (301), Shuttle/PAM launch vehicle (302, 303)
Developed for	AT&T
Developed by	Hughes Aircraft Company
Operated by	AT&T

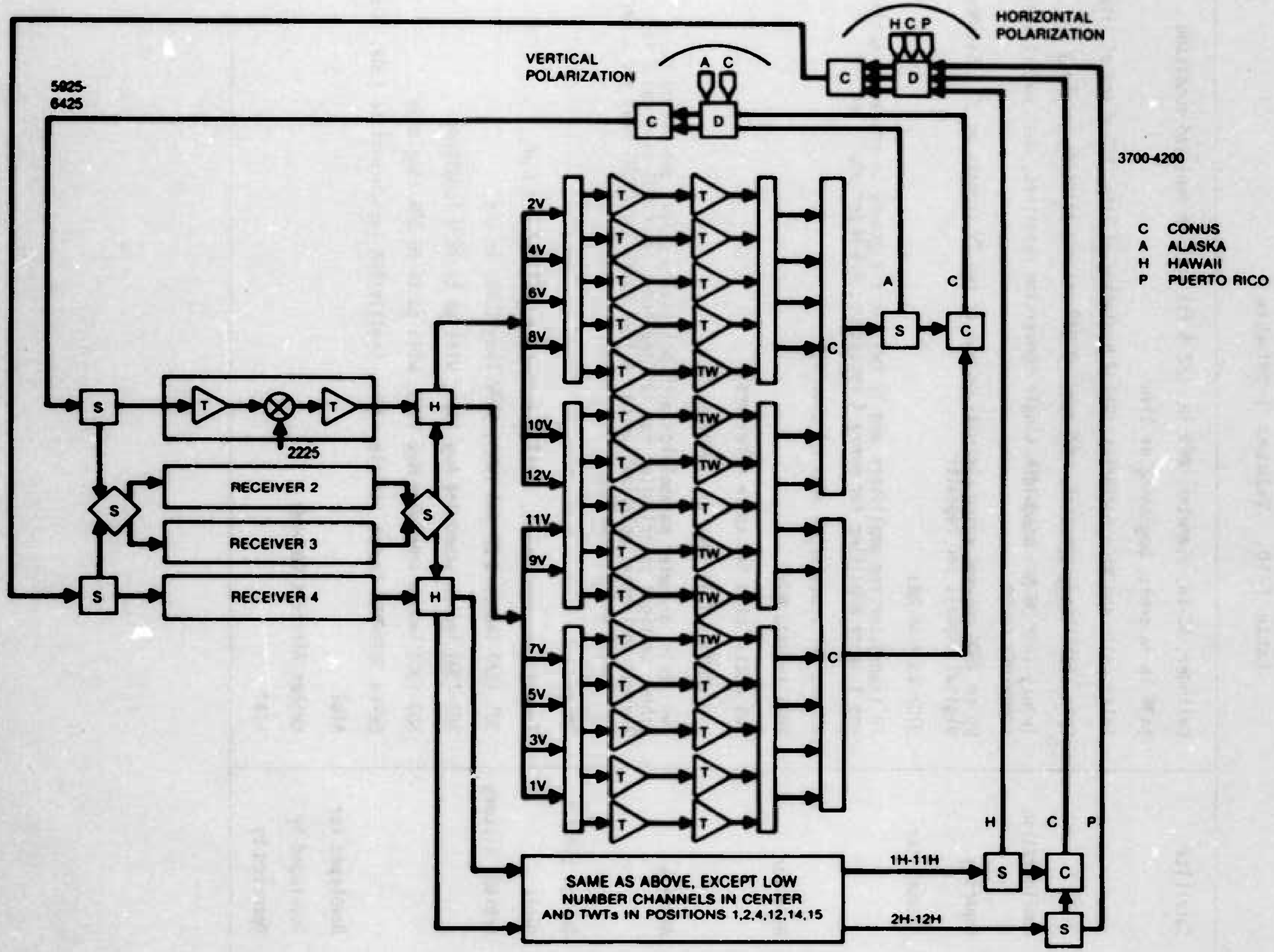


Figure 7-16. Telstar 3 Communication Subsystem

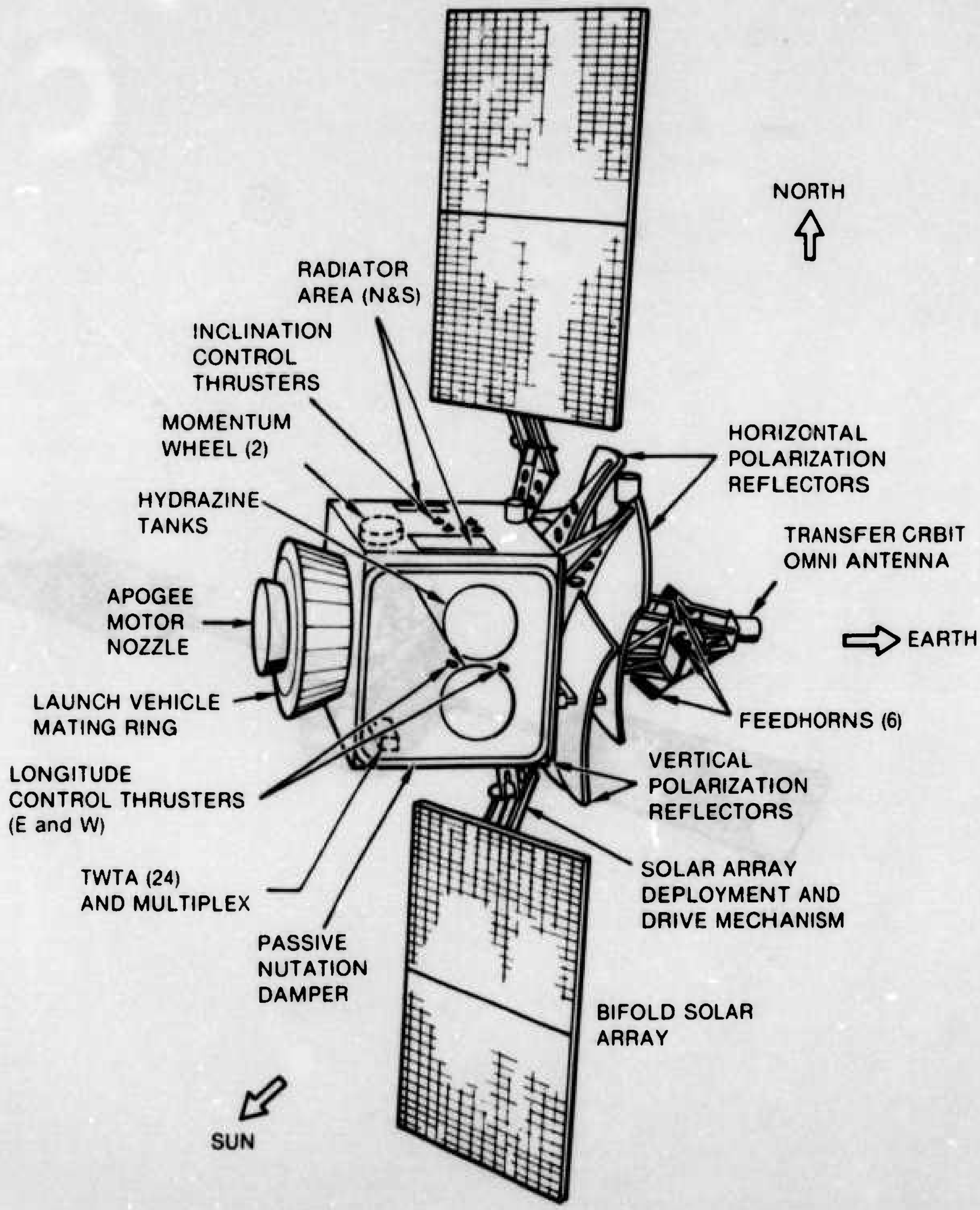


Figure 7-17. RCA Satellite (Number 1 and 2)

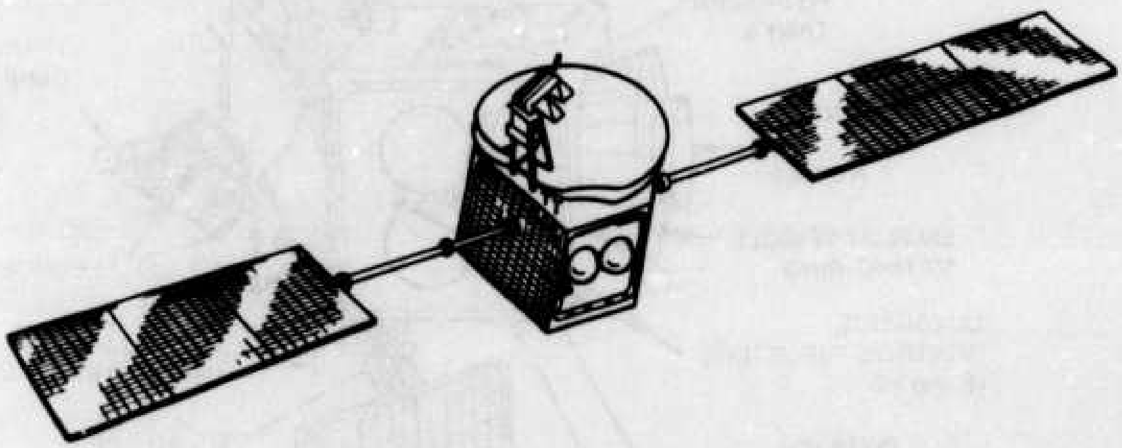
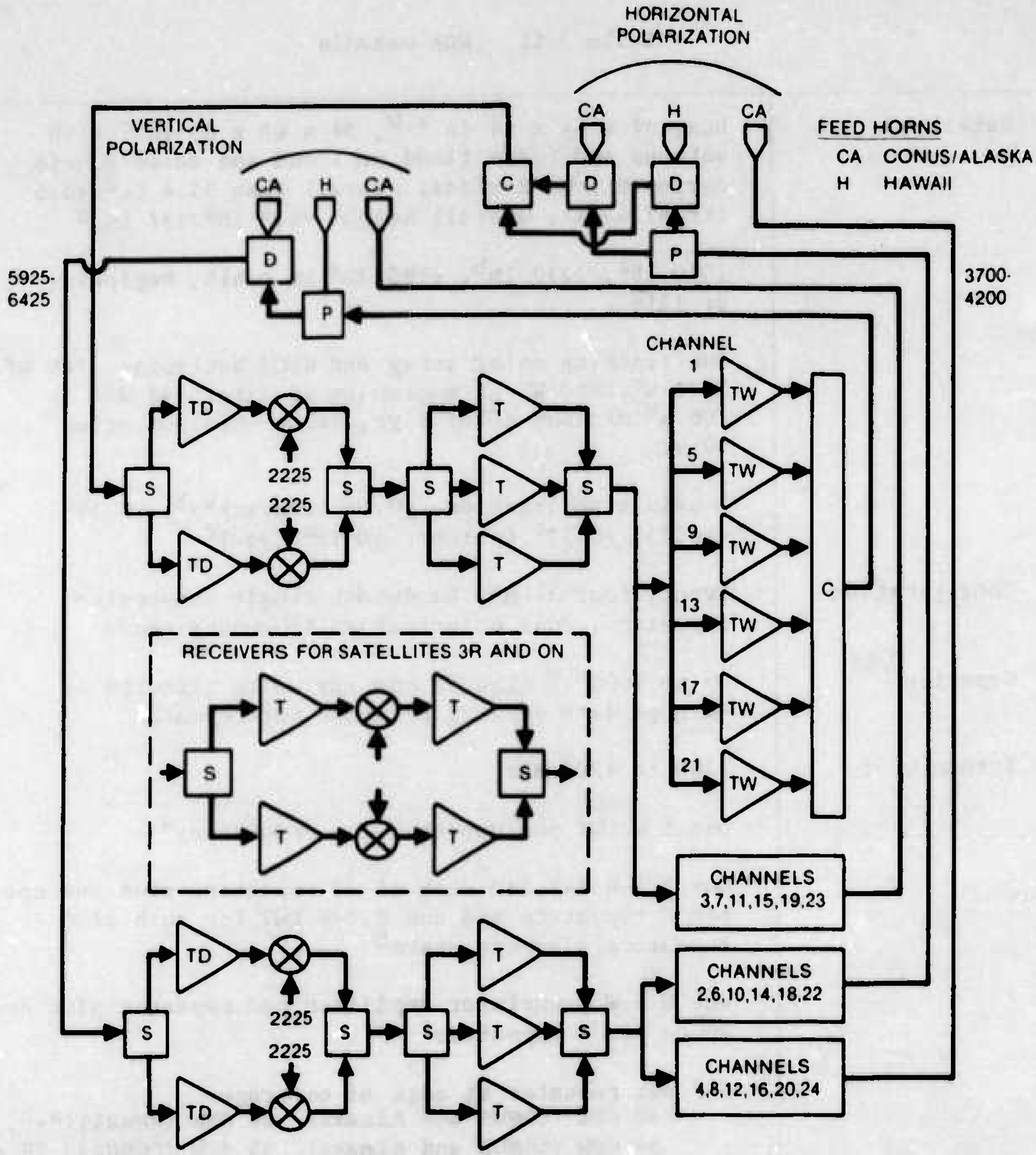


Figure 7-18. RCA Satellite (Number 5 and up)



Notes:

a. Satellites from 3 on have a spare amplifier for each group of 6
b. Satellites from 5 on have transistor amplifiers rather than TWTs
c. Satellites 5 and 1R have additional feed horns for Alaska coverage

Figure 7-19. RCA Satellite Communication Subsystem

Table 7-11. RCA Details

Satellite	Box, 47 x 64 x 44 in.[a,b], 56 x 64 x 69 in.[c] with antenna and feeds fixed on 1 end and solar panels deployed from 2 sides, overall span 31.4 ft[a]/40.5 ft[b]/47.6 ft[c]; overall height ~114 in[a]/137 in.[c]
	1010 lb[a], 1210 lb[b], 1290 lb[c] in orbit, beginning of life
	Sun-tracking solar array and NiCd batteries, 745 W[a]/1000 W[b]/1450 W[c] at beginning of life, 490 W[a]/700 W[b] minimum after 8 yr, 980 W[c] minimum after 10 yr
	3-axis stabilization, $\pm 0.2^\circ$ accuracy[a,b]; $\pm 0.19^\circ$ (roll), $\pm 0.12^\circ$ (pitch), $\pm 0.25^\circ$ (yaw)[c]
Configuration	Twenty-four 34-MHz bandwidth single conversion repeaters, dual polarization frequency reuse
Capacity	Up to 1000[a,b] (1500[c]) one-way voice circuits or 64 Mbps data or 2 TV programs per repeater
Transmitter	3700 to 4200 MHz
	One 5-W TWT per repeater, no redundancy[a]
	One 5.5-W TWT for each of 18 repeaters plus one spare per 6 repeaters and one 8.5-W TWT for each of 6 repeaters plus one spare[b]
	One 8.5-W transistor amplifier per repeater plus one spare per 6 repeaters[c]
	ERP per repeater at edge of coverage: 32 dBW (CONUS and Alaska), 26 dBW (Hawaii)[a,b]; 34 dBW (CONUS and Alaska), 35 dBW (CONUS), 38 dBW (Alaska), 26 dBW (Hawaii)[c]
Receiver	5925 to 6425 MHz
	4 receivers (2 on, 2 standby)
	G/T at edge of coverage: -6 dB/°K[a,b], -3 dB/°K[c] (CONUS and Alaska); -10 dB/°K[a,b], -7 dB/°K[c] (Hawaii)

Table 7-11. RCA Details (Continued)

Antenna	2 antennas (1 for horizontal polarization transmission and reception and 1 for vertical polarization, each with feed horns for CONUS/Alaska coverage and for Hawaii coverage) 33-dB isolation between the 2 polarizations
Design Life	7 yr[a]/8 yr[b]/10 yr[c]
Orbit	Synchronous equatorial; stationkeeping to $\pm 0.1^{\circ}$N-S and E-W
Orbital History	1. Launched 13 Dec 1975, replaced by 1R in summer/fall 1983 2. Launched 26 Mar 1976, replaced by 2R in fall 1983, 119°W longitude 3. Launched 7 Dec 1979, lost at apogee motor firing 3R: Launched 19 Nov 1981, in use as of Aug 1983, 131°W longitude 4: Launched 15 Jan 1982, in use as of Aug 1983, 83°W longitude 5: Launched 28 Oct 1982, in use as of Aug 1983, 143°W longitude 1R: Launched 11 Apr 1983, in use as of Aug 1983, 139°W longitude 2R: Launched 8 Sep 1983, will be in use at 72°W longitude. Delta 3914[a]/3910[b]/3924[c] launch vehicle Additional launches scheduled in 1985-1987 on the Shuttle.
Developed for	RCA Americom and RCA Alascom (Alascom Inc. since 1981)
Developed by	RCA Astro Electronics
Operated by	RCA Americom

[a]Satellites 1 and 2.
[b]Satellites 3, 3R, and 4.
[c]Satellites 5, 1R, and 2R.

Figure 7-20. SBS Satellite

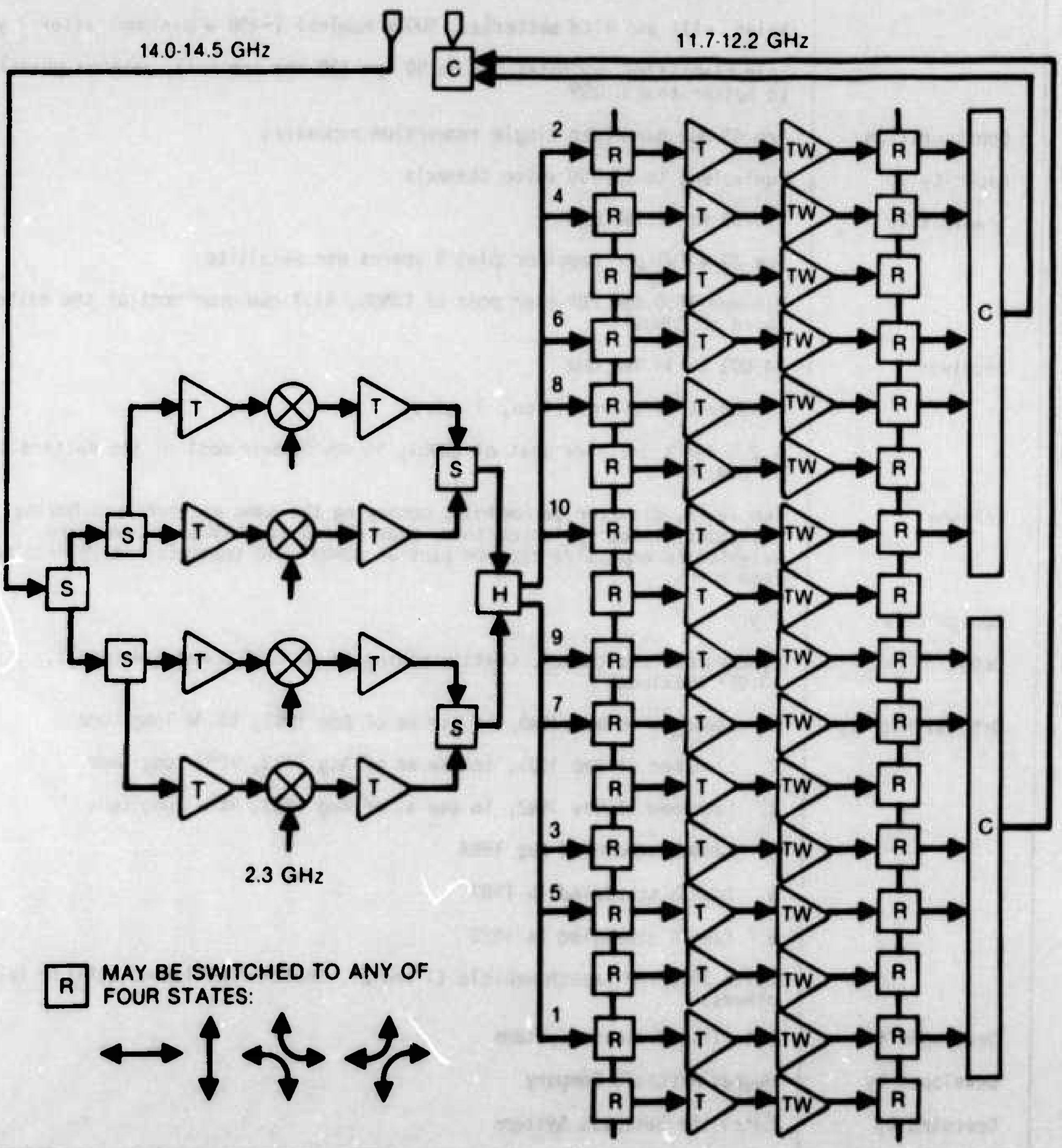


Figure 7-21. SBS Communication Subsystem

Table 7-12. SBS Details

Satellite	Cylinder, 85-in. diameter, 260 in. (21.7 ft) tall in deployed condition
	1220 lb in orbit, beginning of life
	Solar cells and NiCd batteries, 900 W nominal (~830 W minimum) after 7 yr
	Spin-stabilized, gyrostat, 50 to 9? rpm (50 rpm nominal), antenna pointing to better than 0.05°
Configuration	Ten 43-MHz bandwidth single conversion repeaters
Capacity	Equivalent to 13,000 voice channels
Transmitter	11.703 to 12.188 GHz
	One 20-W TWT per repeater plus 6 spares per satellite
	Minimum 40.0-dBW ERP over most of CONUS, 41.7 dBW over most of the eastern third of CONUS[a]
Receiver	14.003 to 14.488 GHz
	Redundant receivers (1 on, 3 spare)
	≥-2.5 dB/°K G/T over most of CONUS, ≥0 dB/°K over most of the eastern third of CONUS[a]
Antenna	Two 72-in. diameter paraboloids occupying the same aperture and having orthogonal linear polarizations, beam shaped for CONUS coverage and weighted to emphasize eastern part of CONUS[a], 10 transmit and 15 receive feed horns
Design Life	7 yr
Orbit	Synchronous equatorial, stationkeeping to ±0.03°N-S and E-W (goal), ±0.05° (maximum)
Orbital History	1. Launched 15 Nov 1980, in use as of Aug 1983, 100°W longitude
	2. Launched 24 Sep 1981, in use as of Aug 1983, 97°W longitude
	3. Launched 11 Nov 1982, in use as of Aug 1983, 94°W longitude
	4. Launch scheduled Aug 1984
	5. Launch scheduled in 1987
	6. Launch scheduled in 1988
	Delta 3910/PAM launch vehicle (1 and 2), Shuttle/PAM launch vehicle (all others)
Developed for	Satellite Business Systems
Developed by	Hughes Aircraft Company
Operated by	Satellite Business Systems

[a]See Figure 7-22 for details.

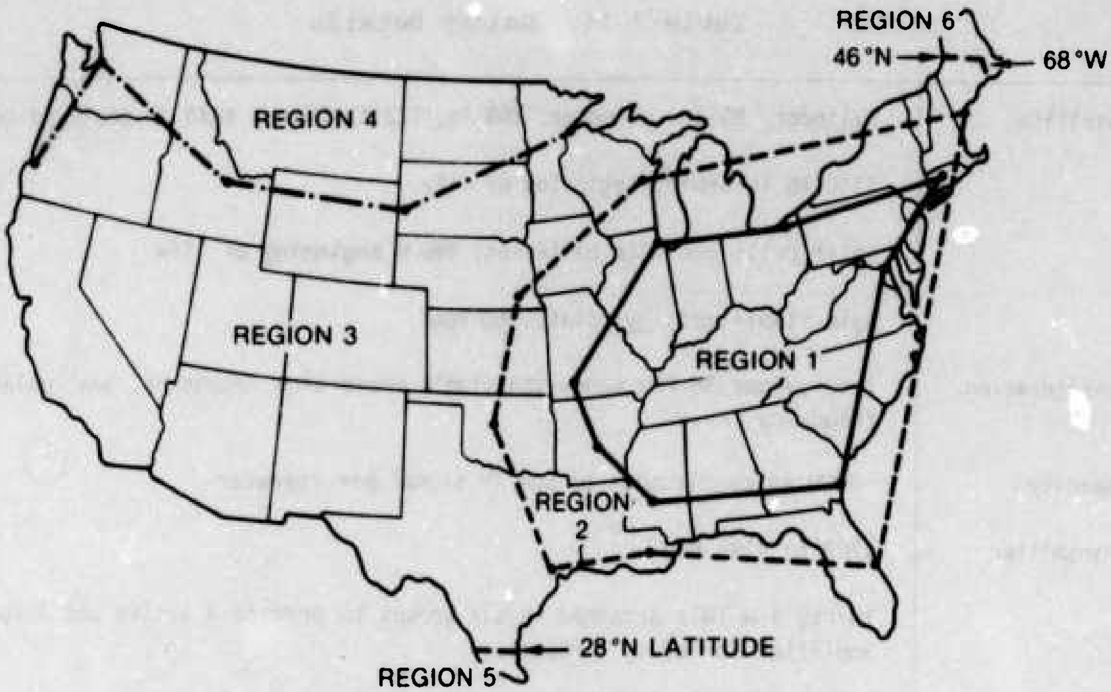


Figure 7-22. SBS Coverage Regions

Table 7-13. Minimum Performance Requirements

Region	Receive G/T (dB/°K)	Transmit ERP (dBW)
1	+2.0	43.7
2	0	41.7
3	-2.5	40.0
4	-5.5	37.0
5	-4.5	38.0
6	-5.5	39.0
San Francisco	+0.5	42.0
Los Angeles	-0.3	41.2

Table 7-14. Galaxy Details

Satellite	Cylinder, 85-in. diameter, 269 in. (22 ft 5 in.) tall in deployed condition
	1140 lb in orbit, beginning of life
	Solar cells and NiCd batteries, 990 W beginning of life
	Spin-stabilized, gyrostat, ~60 rpm
Configuration	Twenty-four 36-MHz bandwidth single conversion repeaters, dual polarization frequency reuse
Capacity	~1000 voice circuits or one TV signal per repeater
Transmitter	3702 to 4198 MHz
	Thirty 9-W TWTs arranged in six groups to provide 4 active and 1 spare amplifier for every 4 repeaters
	ERP: 34 dBW (CONUS), 30 dBW (Alaska), 29 dBW (Hawaii, Puerto Rico)
Receiver	5927 to 6423 MHz
	Two active plus two spare receivers
	$\geq$-5 dB/$^{\circ}$K G/T
Antenna	Two 72-in. diameter paraboloids with polarizing grids, one behind the other; each handles one of two orthogonal linear polarizations
Design life	9 yr
Orbit	Synchronous equatorial, stationkeeping to $\pm 0.1^{\circ}$N-S and E-W
Orbital History	1. Launched 28 Jun 1983, in use, 134°W longitude
	2. Launched 22 Sep 1983, in use, 74°W longitude
	3. Launch scheduled Jul 1984, will go to 93.5°W longitude
	Delta 3920/PAM launch vehicle
Developed for	Hughes Communications Inc./Hughes Galaxy Inc.
Developed by	Hughes Aircraft Company
Operated by	Hughes Communications Inc./Hughes Galaxy Inc.

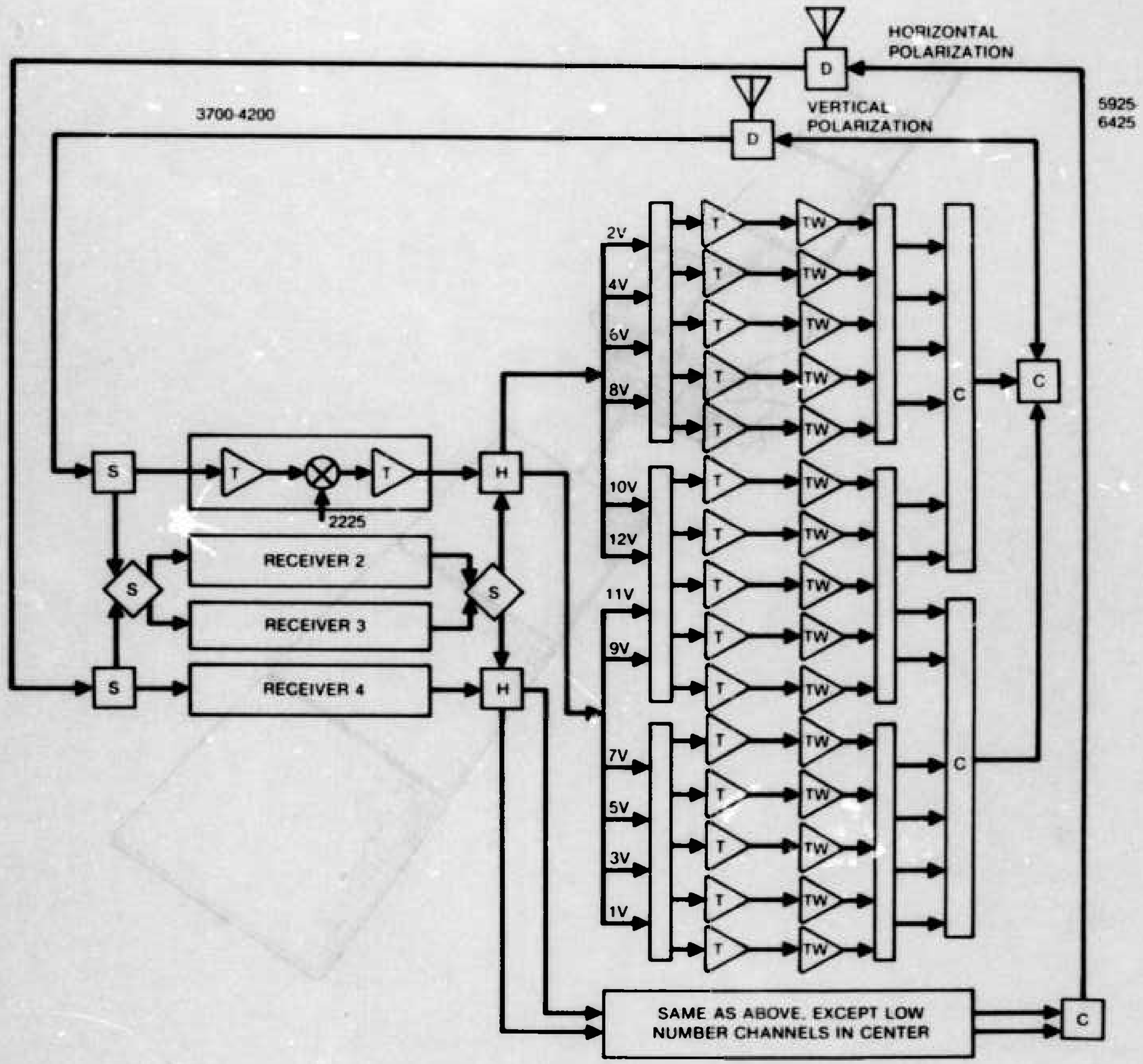


Figure 7-23. Galaxy Communication Subsystem

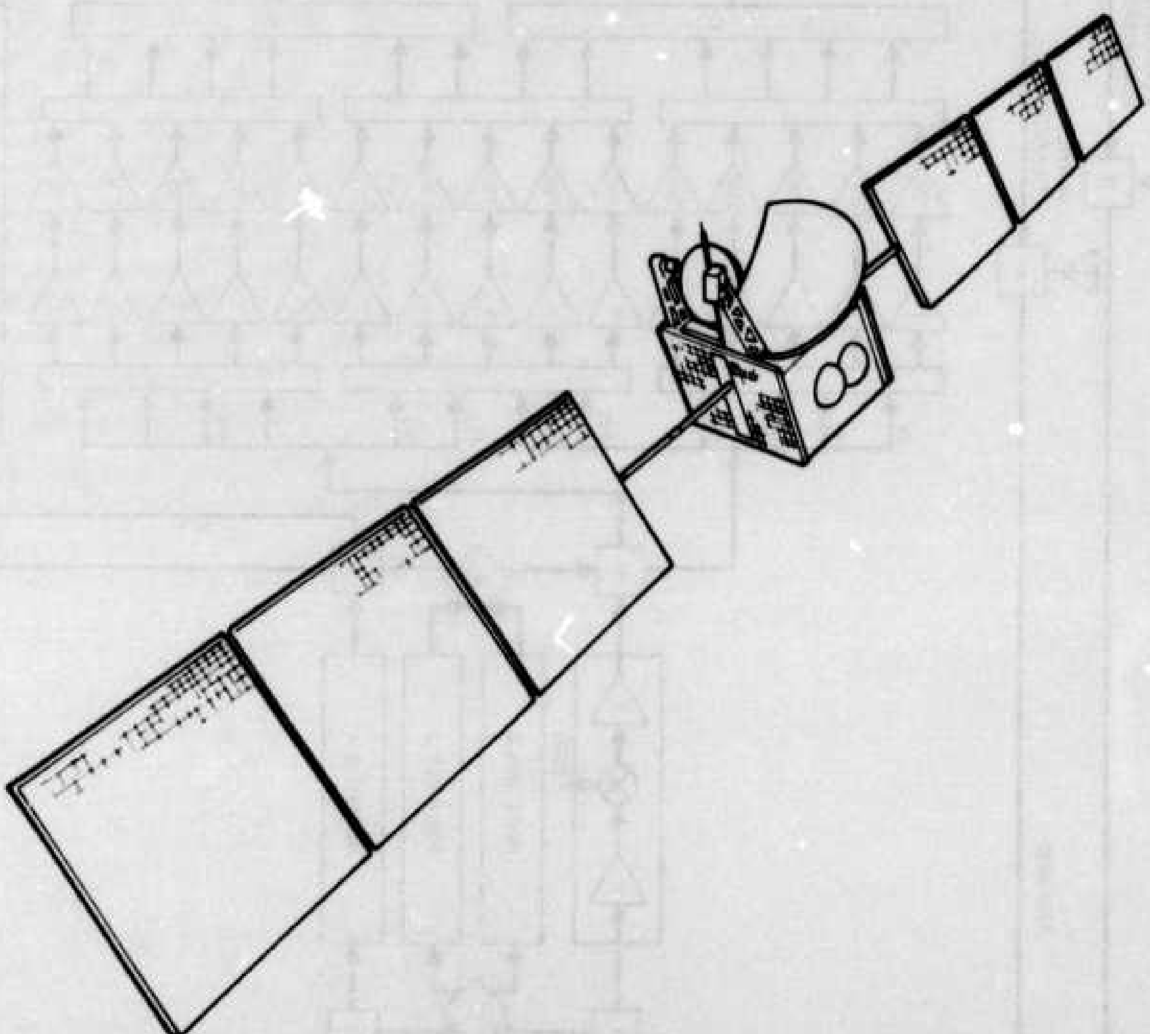


Figure 7-24. Spacenet Satellite

Table 7-15. Spacenet Details

Satellite	Box, about 5 ft on a side, with antennas and feed fixed on the earth-viewing face; solar panels deployed from north and south faces; span across solar panels about 48 ft, height including antenna feeds about 11 ft
	1410 lb in orbit, beginning of life
	Sun tracking solar array and NiH_2 batteries, ~1300 W minimum at end of life
	3-axis stabilization, ~$\pm 0.2^{o}$ accuracy
Configuration	4/6 GHz: twelve 36-MHz bandwidth and six 72-MHz bandwidth single conversion repeaters, dual polarization frequency reuse.
	12/14 GHz: six 72-MHz bandwidth repeaters
Capacity	~1000 voice circuits or 1 TV signal per 36-MHz bandwidth
Transmitter	4/6 GHz: (36-MHz repeaters) 3702 to 4178 MHz, one 8.5-W transistor amplifier per repeater, ERP 34 dBW (CONUS), 28 dBW (Alaska), 25 dBW (Hawaii, Puerto Rico)
	(72-MHz repeaters) 3724 to 4196 MHz, one 16-W TWT per repeater, ERP 36 dBW (CONUS), 32 dBW (Alaska), 28 dBW (Hawaii, Puerto Rico)
	12/14 GHz: 11704 to 12176 MHz; one 16-W TWT per repeater; 41 dBW ERP (CONUS)
	One spare amplifier for every six repeaters
Receiver	4/6 GHz: two active plus two spare receivers
	(36-MHz repeaters) 5927 to 6403 MHz, G/T -5 dB/^{o}K (CONUS), -7 to -9 dB/^{o}K (Alaska, Hawaii, Puerto Rico)
	(72-MHz repeaters) 5949 to 6421 MHz, G/T -2 to -3 dB/^{o}K (CONUS), -7 dB/^{o}K (Alaska, Hawaii)
	12/14 GHz: one active plus one spare receiver, 14004 to 14476 MHz, -3 dB/^{o}K G/T (CONUS)
Antenna	4/6 GHz: two paraboloids, ~4 x 5 ft, sharing same physical aperture, each with an embedded grid for one of two orthogonal linear polarizations
	12/14 GHz: one paraboloid, linear polarization
Design Life	7.5 yr
Orbit	Synchronous equatorial, stationkeeping to $\pm 0.1^{o}$N-S and E-W
Orbital History	1. Launch scheduled May 1984, will go to 122^{o}W longitude
	2. Launch scheduled Sep 1984, will go to 69^{o}W longitude
	3. Launch scheduled Feb 1985, will go to 91^{o}W longitude
	Ariane launch vehicle
	Two Shuttle launches are scheduled in 1987
Developed for	GTE Spacenet Corp.
Developed by	RCA Astro Electronics
Operated by	GTE Spacenet Corp.

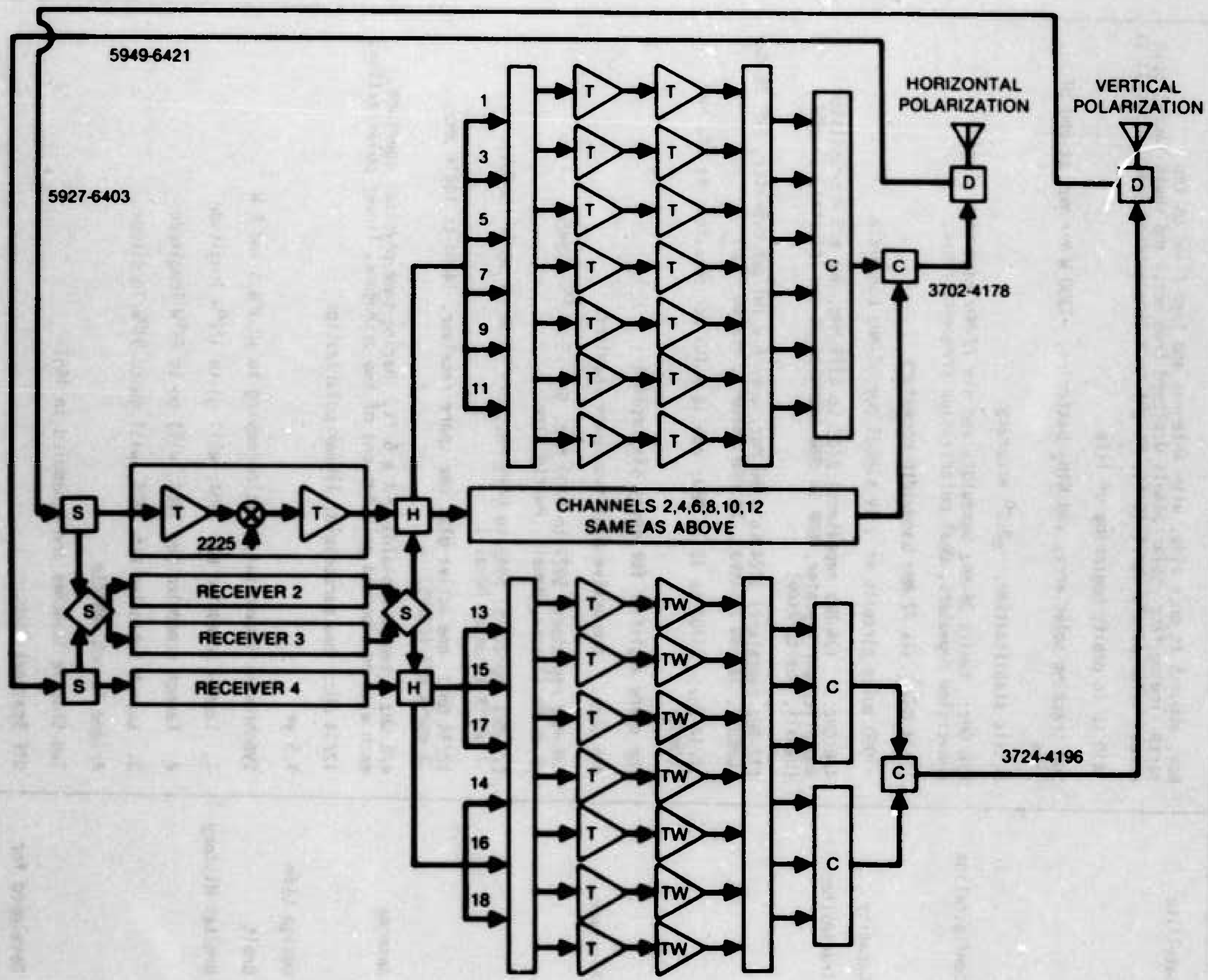


Figure 7-25. Spacenet 4/6-GHz Communication Subsystem

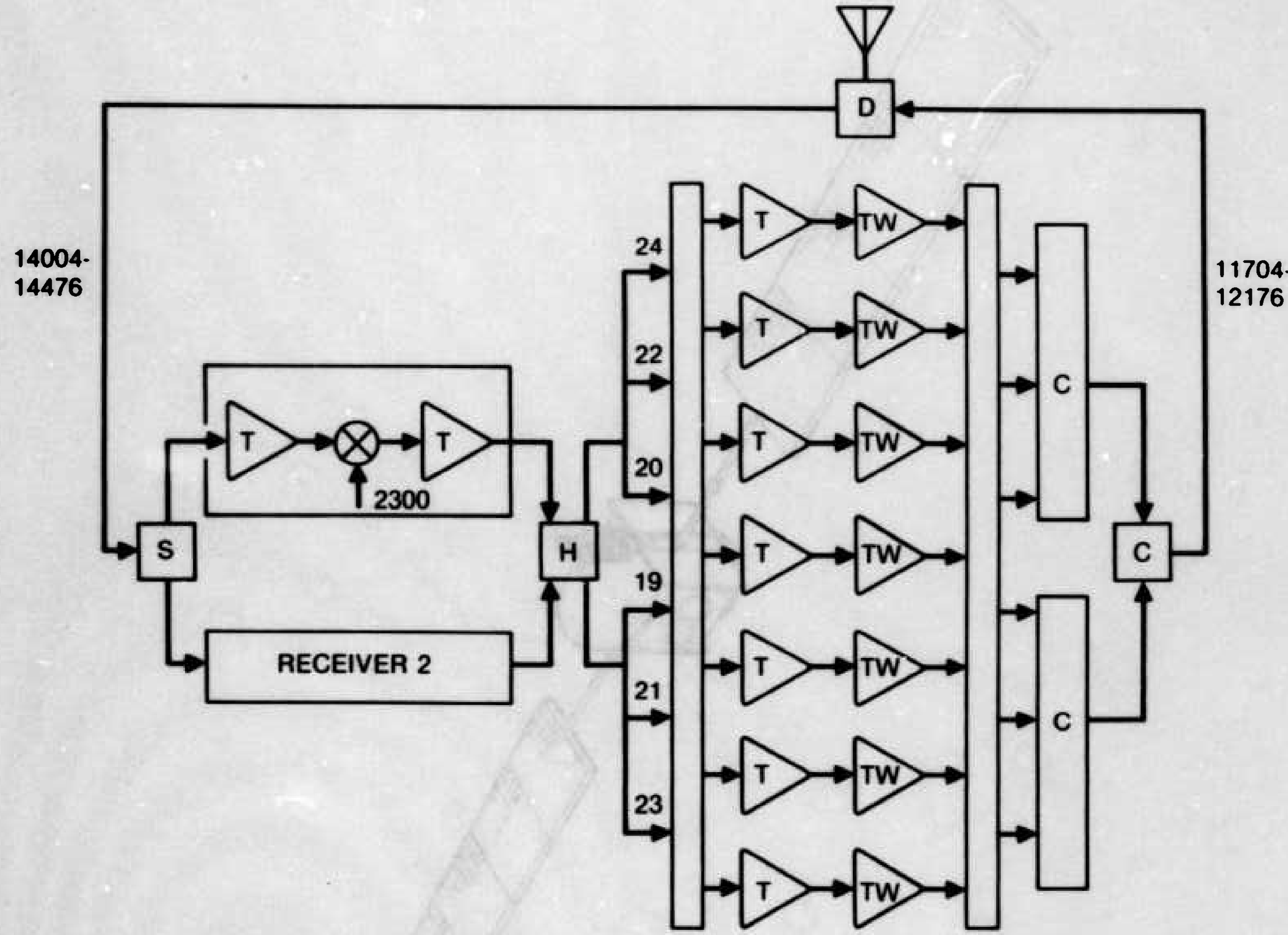


Figure 7-26. Spacenet 12/14-GHz Communication Subsystem

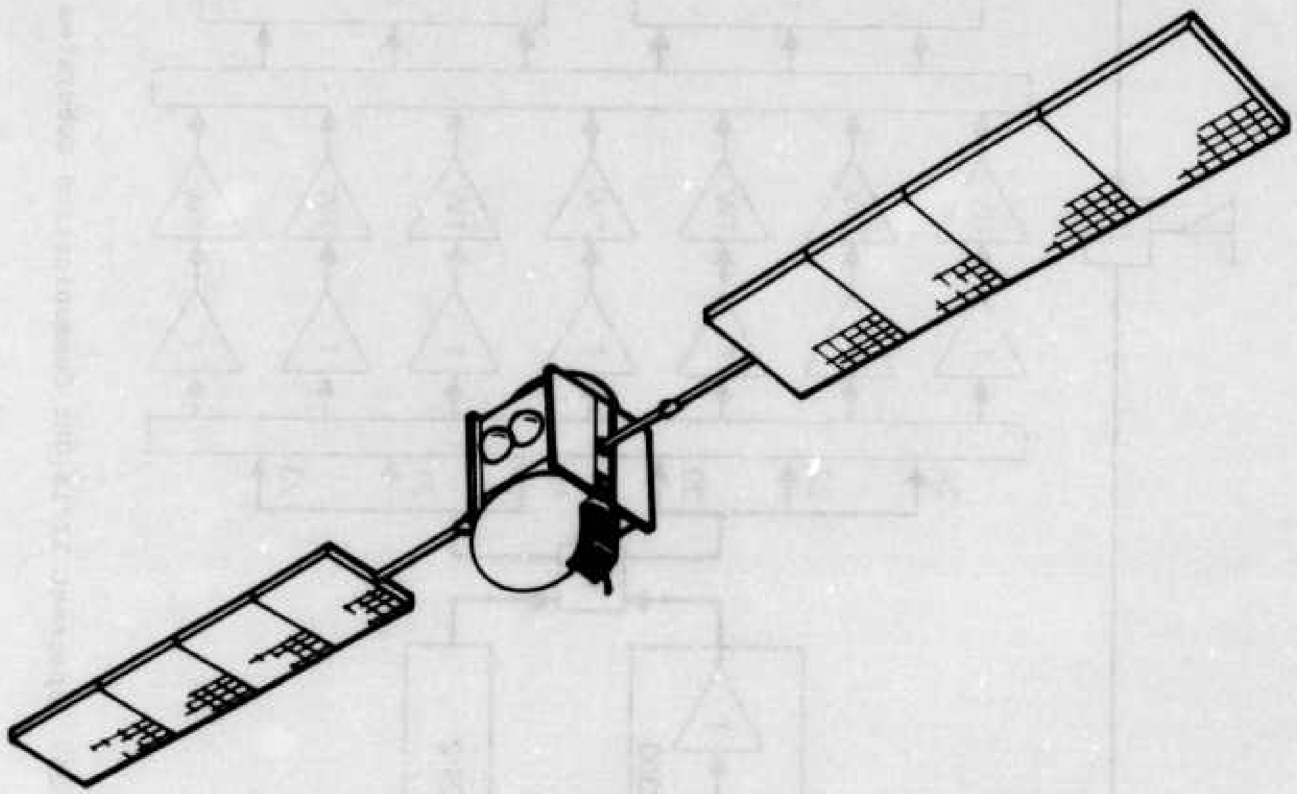


Figure 7-27. GStar Satellite

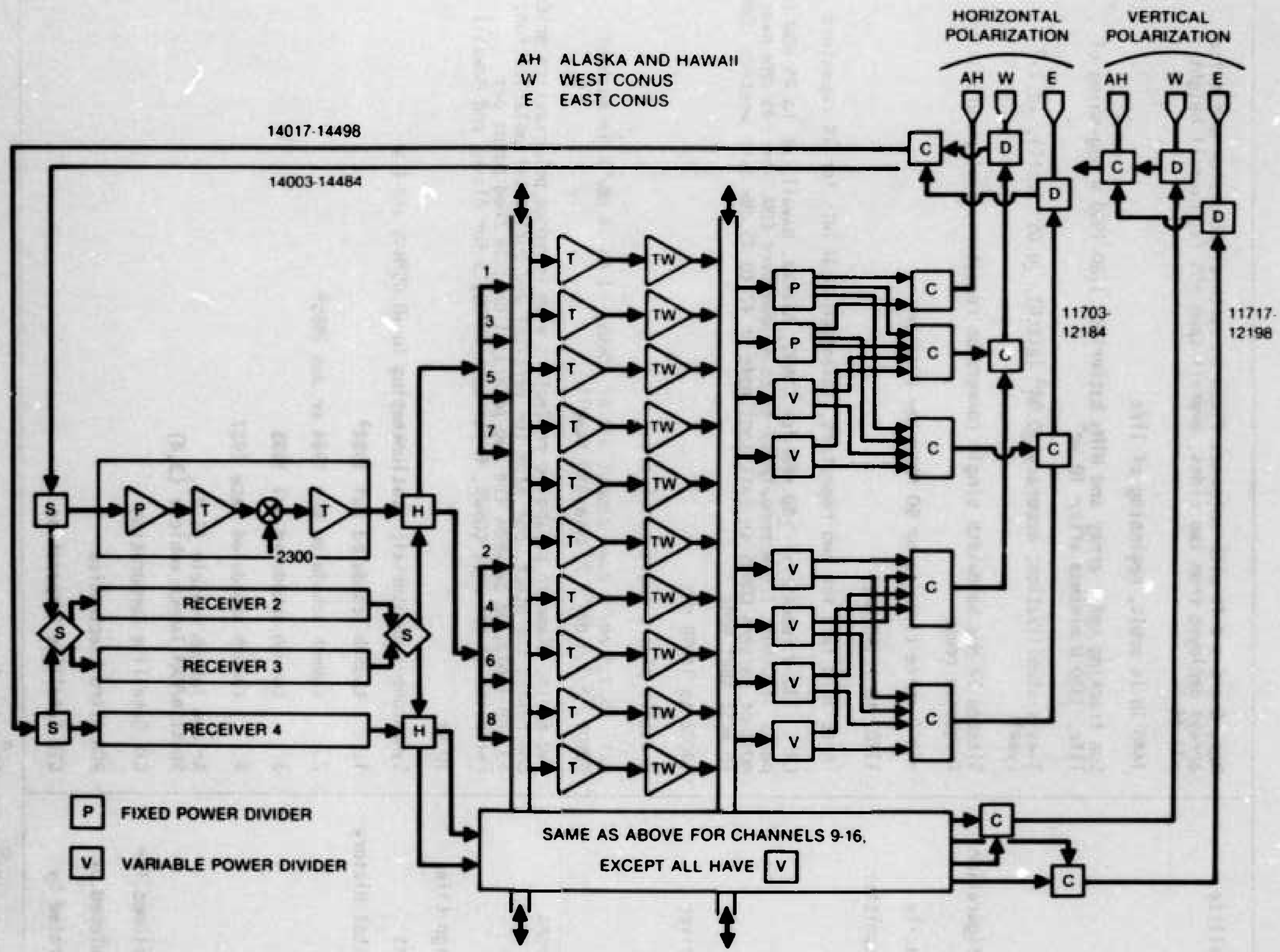


Figure 7-28. GStar Communication Subsystem

Table 7-16. GStar Details

Satellite	Box, 6 x 6 x 8 ft with antennas fixed on earth-viewing side and solar arrays deployed from two sides, overall span ~55 ft, overall height ~11 ft
	1440 lb in orbit, beginning of life
	Sun tracking solar array and NiH_2 batteries, 1700-1900 W beginning of life, 1330 W minimum after 10 yr
	3-axis stabilization; accuracy $\pm 0.04^{\circ}$ (pitch), $\pm 0.05^{\circ}$ (roll), $\pm 0.13^{\circ}$ (yaw)
Configuration	Sixteen 54-MHz bandwidth single conversion repeaters, dual polarization frequency reuse
Capacity	~1800 voice circuits or 90 Mbps per repeater
Transmitter	11703 to 12198 MHz
	Three 30-W TWTs for two repeaters, seventeen 20-W TWTs for 14 repeaters
	ERP: (30-W repeaters) $\geq$40 dBW for CONUS, Alaska, Hawaii, up to 45 dBW in parts of CONUS; (20-W repeaters) 40 to 45 dBW over CONUS or ~45 dBW over most of eastern CONUS in east spot mode or 42 to 45 dBW over western CONUS in west spot mode
Receiver	14003 to 14498 MHz
	2 active plus 2 spare receivers
	G/T: $\geq$-1.5 dB/$^{\circ}$K over almost all of CONUS, +1 to +4 dB/$^{\circ}$K in much of CONUS, $\geq$-3.5 dB/$^{\circ}$K Alaska and Hawaii
Antenna	Two 60-in. diameter parabolic reflectors with embedded polarization grids, one behind the other, one each for vertical and horizontal polarization; $\geq$33 dB isolation between the two polarizations; 16 feed horns per reflector (7 for west CONUS, 6 for east CONUS, 3 for Alaska and Hawaii)
Design Life	10 yr
Orbit	Synchronous equatorial; stationkeeping to $\pm 0.05^{\circ}$N-S and E-W
Orbital History	1. Launch scheduled Jul 1984[a]
	2. Launch scheduled Nov 1984 or Jan 1985[a]
	3. Launch scheduled Jul 1985
	4. Launch scheduled late 1987
	Ariane launch vehicle (1,2), Shuttle/PAM launch vehicle (3,4)
Developed for	GTE Satellite Corporation
Developed by	RCA Astro Electronics
Operated by	GTE Satellite Corporation

[a]Will go to 103°W and 105°W longitude.

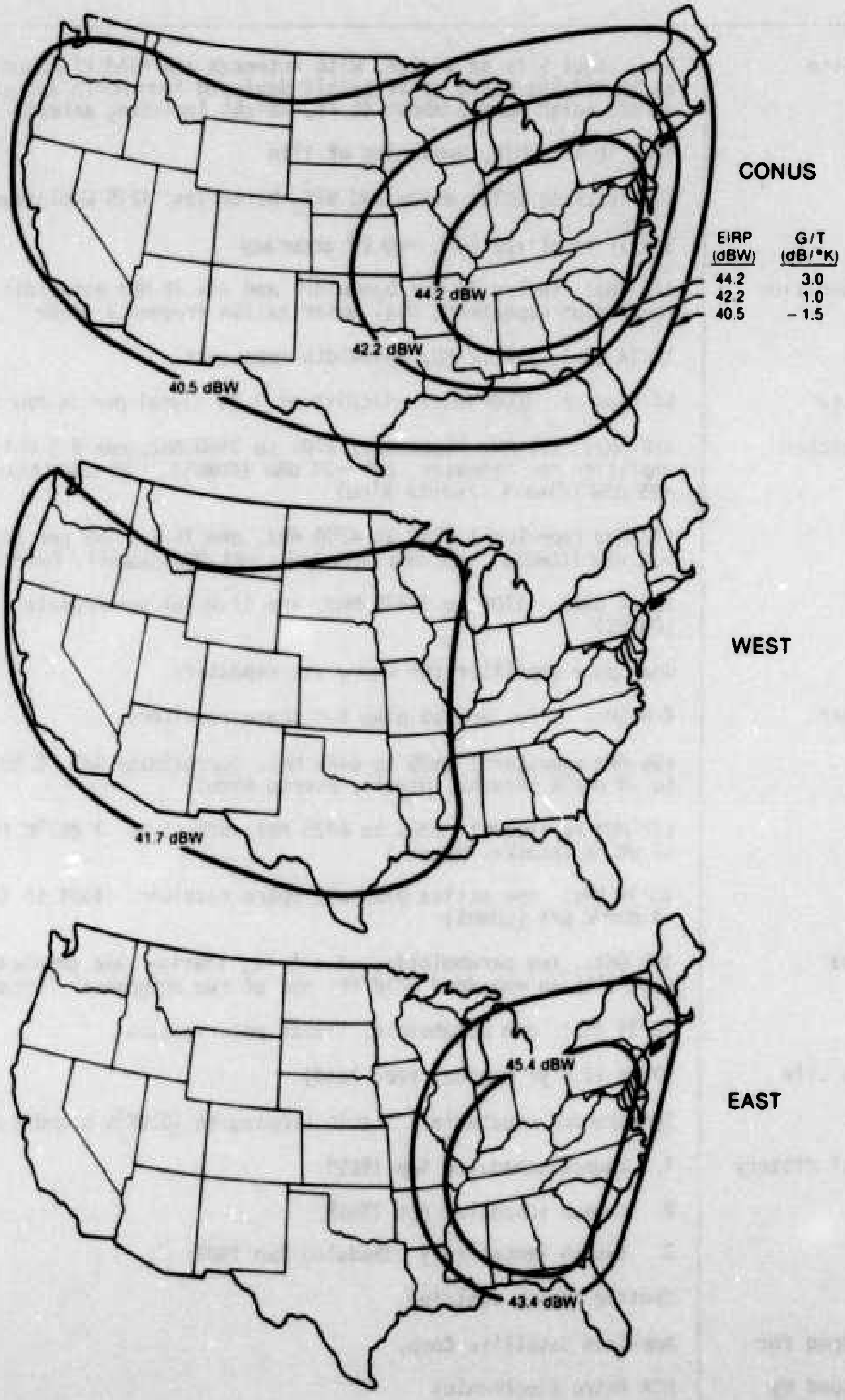


Figure 7-29. GStar Beam Patterns

Table 7-17. ASC Details

Satellite	Box, about 5 ft on a side, with antennas and feed fixed on the earth-viewing face; solar panels deployed from north and south faces; span across solar panels about 48 ft, height including antenna feeds about 11 ft
	1467 lb in orbit, beginning of life
	Sun tracking solar array and NiH_2 batteries, 1215 W minimum after 10 yr
	3-axis stabilization, $\sim\pm 0.2^{o}$ accuracy
Configuration	4/6 GHz: twelve 36-MHz bandwidth and six 72-MHz bandwidth single conversion repeaters, dual polarization frequency reuse
	12/14 GHz: six 72-MHz bandwidth repeaters
Capacity	64 Mbps or ~1000 voice circuits or 1 TV signal per 36-MHz bandwidth
Transmitter	4/6 GHz: (36-MHz repeaters) 3700 to 3960 MHz, one 8.5-W transistor amplifier per repeater, ERP ~34 dBW (CONUS), ~28 dBW (Alaska), ~25 dBW (Hawaii, Puerto Rico)
	(72-MHz repeaters) 3940 to 4200 MHz, one 16.6-W TWT per repeater, ERP ~36 dBW (CONUS), ~32 dBW (Alaska), ~28 dBW (Hawaii, Puerto Rico)
	12/14 GHz: 11704 to 12176 MHz; one 17-W TWT per repeater; ~41 dBW ERP (CONUS)
	One spare amplifier for every six repeaters
Receiver	4/6 GHz: two active plus two spare receivers
	(36-MHz repeaters) 5925 to 6185 MHz, approximate G/T -5 dB/^{o}K (CONUS), -7 to -9 dB/^{o}K (Alaska, Hawaii, Puerto Rico)
	(72-MHz repeaters) 6165 to 6425 MHz, G/T -2 to -3 dB/^{o}K (CONUS), -7 dB/^{o}K (Alaska, Hawaii)
	12/14 GHz: one active plus one spare receiver, 14004 to 14476 MHz, -3 dB/^{o}K G/T (CONUS)
Antenna	4/6 GHz: two paraboloids, ~4 x 5 ft, sharing same physical aperture, each with an embedded grid for one of two orthogonal linear polarizations
	12/14 GHz: one paraboloid, linear polarization
Design Life	10 yr (8.5 yr nominal fuel load)
Orbit	Synchronous equatorial, stationkeeping to $\pm 0.05^{o}$N-S and E-W
Orbital History	1. Launch scheduled Sep 1985[a]
	2. Launch scheduled Oct 1986[a]
	3. Launch tentatively scheduled Jan 1987
	Shuttle launch vehicle
Developed for	American Satellite Corp.
Developed by	RCA Astro Electronics
Operated by	American Satellite Corp.

[a] Will go to 81^{o}W and 128^{o}W longitude.

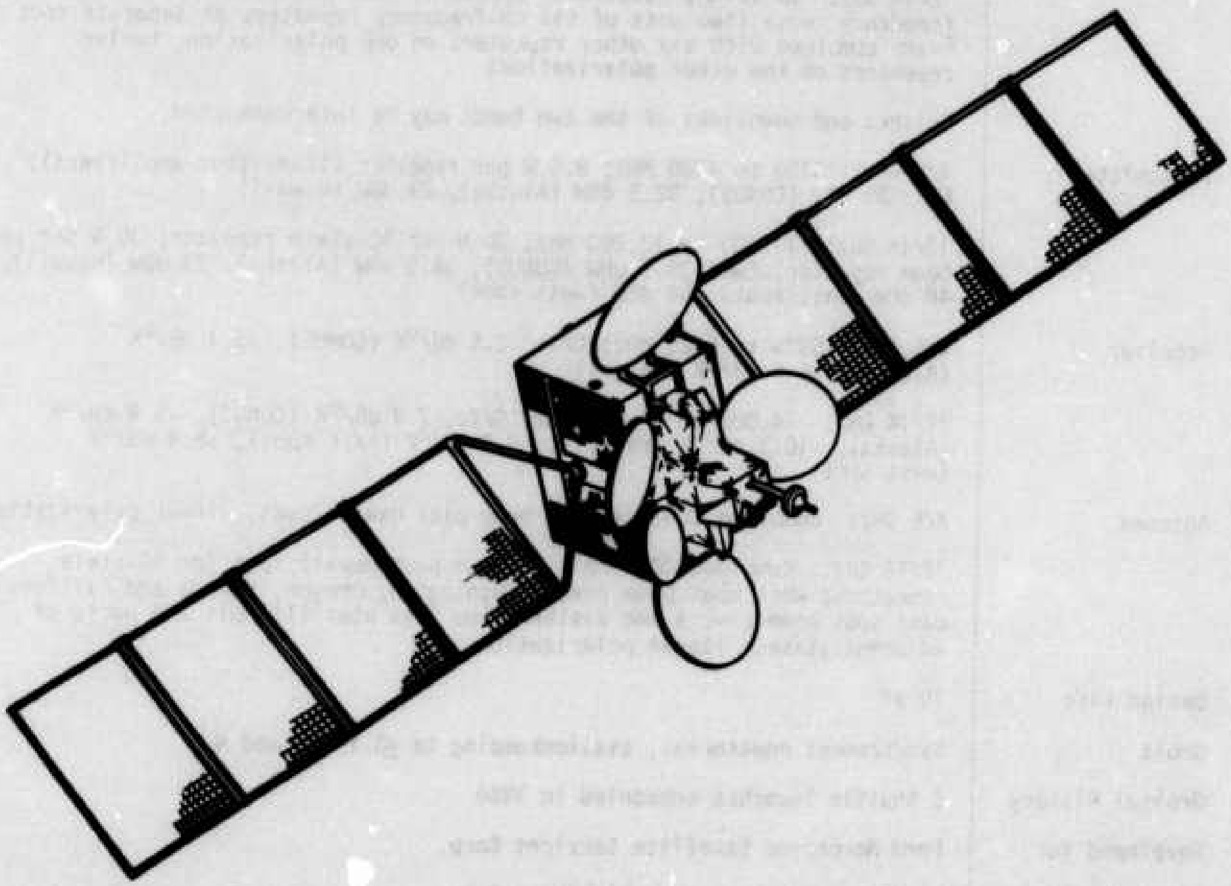


Figure 7-30. Proposed Fordsat Satellite

Table 7-18. Proposed Fordsat Details

Satellite	Rectangular box, ~6 ft on a side; ~80 ft span of deployed solar array ~3400 lb in orbit Sun tracking solar arrays, >2 kW at beginning of life Three-axis stabilization, antenna pointing accuracy $\pm 0.15^{\circ}$ (pitch and roll), $\pm 0.35^{\circ}$ (yaw)
Configuration	4/6 GHz: 24 36-MHz bandwidth repeaters, dual polarization frequency reuse 12/14 GHz: 30 36-MHz bandwidth repeaters, dual polarization and dual beam frequency reuse (two sets of six co-frequency repeaters on separate spot beams combined with six other repeaters on one polarization, twelve repeaters on the other polarization) Uplinks and downlinks of the two bands may be interconnected.
Transmitter	4/6 GHz: 3700 to 4200 MHz; 8.5 W per repeater (transistor amplifiers); ERP: 35 dBW (CONUS); 32.5 dBW (Alaska), 29 dBW (Hawaii) 12/14 GHz: 11,700 to 12,200 MHz; 20 W per 50-state repeater; 30 W per spot beam repeater; ERP: 39.5 dBW (CONUS), 36.5 dBW (Alaska), 33 dBW (Hawaii), 48 dBW (east spot), 50 dBW (west spot)
Receiver	4/6 GHz: 5925 to 6425 MHz; G/T: -2.6 dB/°K (CONUS), -5.1 dB/°K (Alaska), -8.6 dB/°K (Hawaii) 12/14 GHz: 14,000 to 14,500 MHz; G/T: -2.8 dB/°K (CONUS), -5.8 dB/°K (Alaska), -10.3 dB/°K (Hawaii), +3.9 dB/°K (east spot), +5.9 dB/°K (west spot)
Antenna	4/6 GHz: combined CONUS/Alaska beam plus Hawaii spot, linear polarization 12/14 GHz: combined CONUS/Alaska beam plus Hawaii spot for 50-state repeaters; west spot beam covers Washington, Oregon, Nevada and California; east spot beam covers the eastern time zone plus Illinois and parts of adjacent states; linear polarization
Design Life	10 yr
Orbit	Synchronous equatorial, stationkeeping to $\pm 0.1^{\circ}$ E-W and N-S
Orbital History	3 Shuttle launches scheduled in 1988
Developed for	Ford Aerospace Satellite Services Corp.
Developed by	Ford Aerospace and Communications Corp.

7.3 MARISAT (Refs. 144, 150, 160, 249-253, 409, 477-497)

Marisat was developed to provide communications between ships and shore stations. During its first years of operation, the primary user was the U. S. Navy for whom it filled part of the gap between the end of Tacsat and LES-6 operations and the beginning of FLTSATCOM operations. For this reason, the satellite is sometimes called Gapsat or Gapfiller. Marisat also provides service for commercial shippers.

7.3.1 Satellite

Marisat is a derivative of the Anik satellite. The basic structure and support subsystems are very similar to Anik, but the solar array diameter is 13 percent larger, thus increasing its output power. Marisat is heavier than Anik and uses the larger payload capacity of the Delta 2914 launch vehicle. Figure 7-31 is a picture of Marisat.

Marisat has a new communication subsystem (Figure 7-32). Three UHF channels are provided for Navy use, two with 25-kHz bandwidth and one with 500-kHz bandwidth. Each channel has a redundant transistor amplifier. For commercial use, there are two 4-MHz bandwidth channels, one for ship-to-shore communications and one for shore-to-ship. These channels use L-band frequencies between the satellite and ships, and C-band between the satellite and shore stations. TWTs are used for both L-and C-band transmissions, and the L-band TWT can be commanded to any of three power levels. The low power level was used when all Navy channels were operating; as Navy requirements decrease or finish, the higher power levels are used.

Marisat has nine communication antennas. Three helices backed by truncated cones form a UHF array with a 30 deg beamwidth. A narrower beamwidth is not practical because of the larger antenna that would be required. Four smaller cone-helix antennas form an L-band array with a 20 deg beamwidth. Two earth coverage horns are used at C-band, one for transmitting and one for receiving. Other Marisat details are given in Table 7-19.

All three Marisat satellites are in orbit. The first was launched in February 1976 and placed over the Atlantic Ocean. It began Navy service in March 1976, but the start of commercial service was delayed until July 1976 because of problems with the C-band equipment. The second Marisat was launched in June 1976 and was providing both naval and commercial service over the Pacific Ocean by August. The third satellite was launched in October 1976 to provide service to the Navy in the Indian Ocean region. Commercial service with this satellite began in November 1978 with a terminal in Japan. Signal-quality reports for both types of service have been good since the system began operating; the expected improvements relative to terrestrial transmission links have been fully realized. The coverage areas of the three satellites are shown in Figure 7-33.

Commercial service began in a limited manner, due to the small number of terminals and because most of the satellite power was required for the Navy channels. Gradually, Navy use decreased and commercial use increased. Commercial services include telex, voice, facsimile, and data (up to 4800 bps) in both directions. These services are used by tankers, cargo, passenger and fishing vessels, off shore oil platforms, and private yachts. In 1981 56 kbps ship-to-shore service was initiated, primarily for data transmissions from seismic survey vessels. On February 1, 1982 control of the three Marisats was transferred to Inmarsat (Section 4.6). By summer 1983, all three satellites were still useable, although only the Pacific satellite was in active service. The other two satellites were spares in the Inmarsat system.

7.3.2 Terminals

The primary Marisat ground terminals are located in Connecticut and California. They are both TT&C terminals and the shore terminals for all commercial communications for the Atlantic and Pacific satellites respectively. A TT&C terminal at Fucino, Italy serves the Indian Ocean satellite. For the TT&C function, the terminals are connected to a system control center in Washington, D. C. where telemetry and tracking data are

processed. Commands are normally initiated at the control center, but can be initiated at the terminal.

The communication terminals are the link between the Marisat system and the regular terrestrial communication networks. The terminals can handle duplex voice and telegraph signals, 2400-bps data, and simplex ship-to-shore data and telegraphy. A computer at each terminal keeps traffic records, assigns satellite channels (i.e., transmission and reception frequencies) to users, and controls transmission path switching. Channel assignments are made in response to calls initiated from ships or through the terrestrial networks. In addition, the shore station can transmit broadcast messages to all ships of a specific company or nationality, or to all ships in a certain geographic area. Signaling related to channel assignments is handled through dedicated "request" (ship-to-shore) and "assignment" (shore-to-ship) channels. Emergency requests are handled with a priority above all other messages.

Two types of ship terminals are possible. The larger is capable of receiving and transmitting one voice channel or other signals of equivalent bandwidth. The smaller terminal would be a receive-only type. Through it, a ship could receive such messages as general news and routing instructions, via teletype, or graphic material such as weather maps via facsimile. The basic characteristics of these terminals and the shore terminals are given in Table 7-20. Approximately 160 of the larger ship terminals were in use by December 1978, growing to 600 in early 1981 and 1000 by January 1982.

The Navy provides its own ship and shore terminals for use with the UHF channels. These terminals are also being used with the FLTSATCOM satellites, but can be tuned to Marisat frequencies. The shore terminals have both communications and network control functions.

Figure 7-31. Marisat Satellite

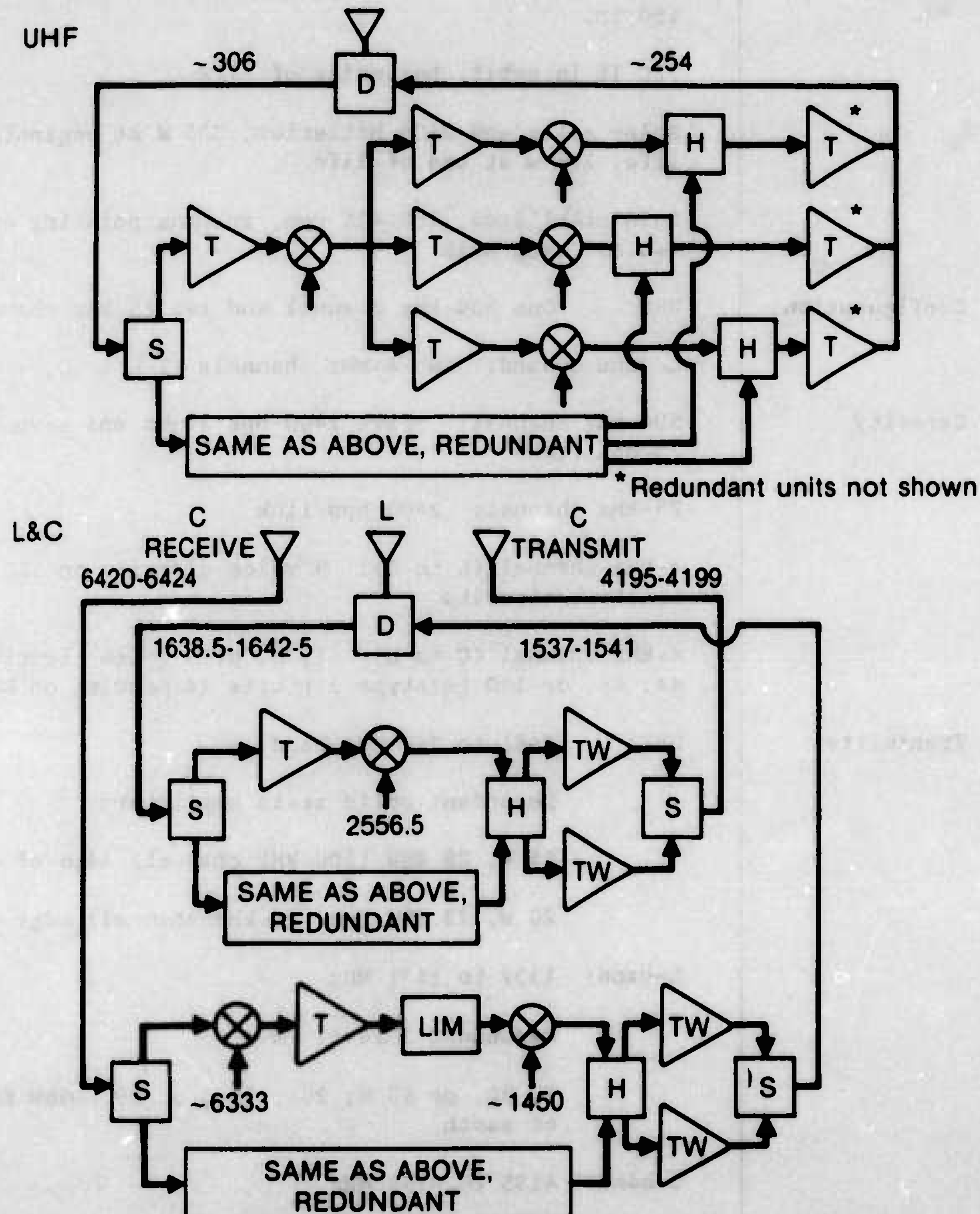


Figure 7-32. Marisat Communication Subsystem

Table 7-19. Marisat Details

Satellite	Cylinder, 85 in. diameter, 63 in. high, overall height 150 in.
	720 lb in orbit, beginning of life
	Solar cells and NiCd batteries, 335 W at beginning of life, 305 W at end of life
	Spin-stabilized, 100 $\pm$15 rpm, antenna pointing error <$\pm$0.65° each axis
Configuration	UHF: One 500-kHz channel and two 25-kHz channels
	L- and C-band: Two 4-MHz channels (1 L to C, 1 C to L)
Capacity	500-kHz channel: ~five 2400-bps links and seventeen 75-bps links
	25-kHz channel: 2400-bps link
	4-MHz channel (L to C): 9 voice circuits or 110 teletype circuits
	4-MHz channel (C to L): 1, 5, or 9 voice circuits and 44, 66, or 110 teletype circuits (depending on ERP)
Transmitter	UHF: 248- to 260-MHz band
	Redundant solid state amplifiers
	65 W, 28 dBW (500-kHz channel) edge of earth
	20 W, 23 dBW (per 25-kHz channel) edge of earth
	L-band: 1537 to 1541 MHz
	Redundant 3-level TWTs
	7, 30, or 60 W; 20-, 26-, or 29.5-dBW ERP edge of earth
	C-band: 4195 to 4199 MHz
	Redundant TWTs

Table 7-19. Marisat Details (Continued)

	5 W, 18.8-dBW ERP (specification) edge of earth (if at saturation; however, this transmitter will always be operated linear), in-orbit ERP 1 to 1.5 dB above specification
Receiver	300- to 312-MHz band, 1638.5 to 1642.5, 6420 to 6424 MHz
	Redundant receivers on each frequency
	Noise figure: 4.2, 4.9, 8.8 dB
	G/T (edge of earth): -18, -17, -25.4 dB/^{o}K
Antenna	UHF: 3 cone-helix antennas, each 48 in. long, 30^{o} beamwidth, 12.1-dB gain (transmit), 12.6-dB gain (receive) at $\pm$9.5^{o}
	L-band: 4 cone-helix antennas, each 15 in. long, ~20^{o} beamwidth, 14.4-dB gain at $\pm$9.5^{o}
	C-band: 2 horns (1 transmit, 1 receive), ~18^{o} beamwidth, 16-dB gain at $\pm$9.5^{o}
	All circular polarization
Design Life	5 yr
Orbit	Synchronous equatorial ($\leq$3.5^{o} inclination), stationkeeping to $\pm$0.5^{o}E-W
Orbital History	1: Launched 19 Feb 1976; 15^{o}W longitude, Inmarsat spare as of Aug 1983
	2: Launched 9 Jun 1976; 176^{o}E longitude, in use as of Aug 1983
	3: Launched 14 Oct 1976; 72^{o}E longitude, Inmarsat spare as of Aug 1983
	Delta 2914 launch vehicle
Developed for	Comsat General Corp. (UHF capacity leased to U.S. Navy)
Developed by	Hughes Aircraft Company
Operated by	Comsat General Corporation

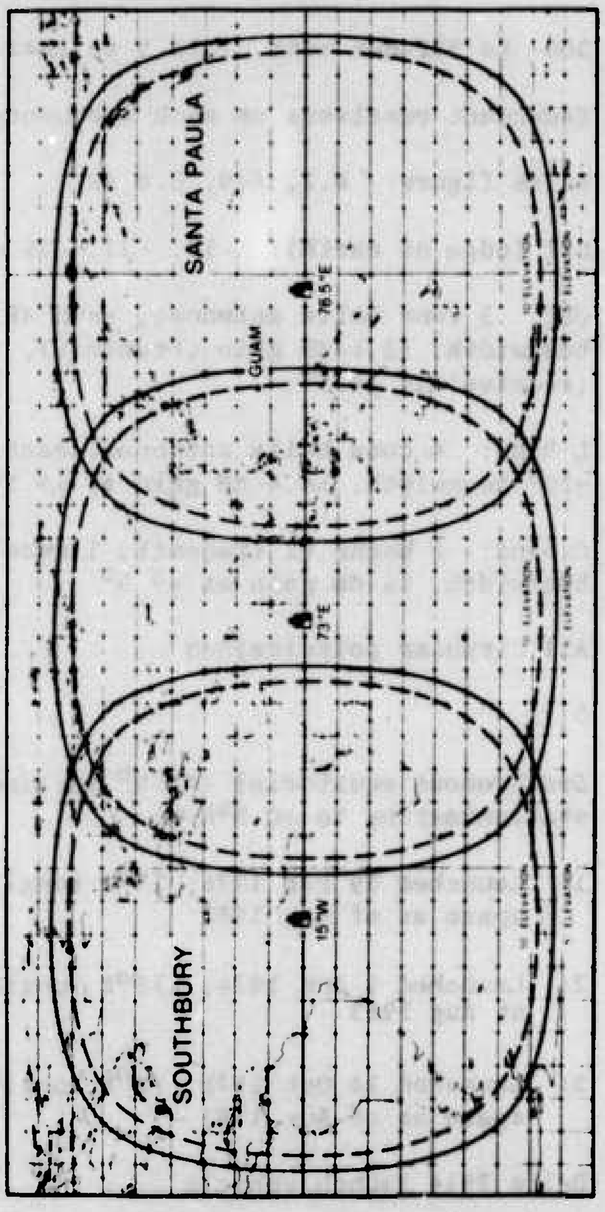


Figure 7-33. Marisat Coverage Areas

Table 7-20. Marisat Terminal Characteristics

Parameter	Shore Stations	Ship Stations: Two-Way Telephone and Telegraphy	Ship Stations: Telegraph and Facsimile Receive Only
Frequency Band	C[a]	L	L
Antenna Diameter, ft	42	4	4
Transmit Gain, dB	56.0	23.5[b]	--
Transmitter Power, W	3000	40	--
ERP, dBW	72-85	36-38	--
Receive Gain, dB	53.2	23.5[b]	23[b]
G/T, dB/^{o}K	31.4	>-4	-4
Beamwidth (transmit/receive), deg	0.26/0.4	10-11	10-11
Polarization	circular	circular	circular

[a]The shore stations can operate at L-band for testing.
[b]Nominal: ERP and G/T are the controlling specifications.

7.4 TDRSS (Refs. 498-532)

Throughout its history, NASA has depended on a worldwide network of ground stations for TT&C support of their satellites. These stations must be connected with CONUS mission control centers by an extensive communications network. However, the contact these stations have with the satellites they support is limited by geometry. Continuous contact is possible for satellites at synchronous altitude, but many satellites are in relatively low altitude orbits ($<$ 1000 nmi). For these satellites, contact durations range from a few to perhaps 20 min, with periods of several hours between contacts. The result is that a mission control center can communicate with a satellite for a small fraction of time (typically $\leq$ 15%). These limitations can be overcome by a Tracking and Data Relay Satellite System (TDRSS). In addition to improving coverage, the TDRSS will allow NASA to close most of its overseas facilities.

Initial studies of the TDRSS were conducted in the early 1970s. Extensive system definition work was done in 1973, and two contractors completed system designs in early 1976. At the same time, NASA, Congress, and the General Accounting Office were analyzing the relative merits of leasing or purchasing the system. The decision was that NASA should lease the system, and at the end of 1976 NASA awarded a contract for the development and ten years of operation of TDRSS. The contract includes both space and ground segments of the system.

The two active TDRSS satellites will be separated about 130 deg in synchronous orbit. This position provides the maximum coverage possible while retaining visibility to a single ground terminal. A spare satellite will be positioned midway between the active satellites. This satellite geometry affords 85 percent coverage to the lowest altitude users ($\sim$110 nmi), increasing to 100 percent at 650 nmi. Coverage for low data rate users decreases above 1100 nmi, but high rate users can be supported up to synchronous altitude. The orbital configuration of the system is shown in Figure 7-34.

TDRSS provides three classes of user service. Each includes forward data links from the ground through TDRSS to users, return data links, and tracking links for gathering data to be used in computing the orbits of user satellites. S-band multiple access (MA) service can accommodate up to 20 simultaneous return links using code division multiple access (CDMA) at rates up to 50 kbps. These links may all go through one TDRS or be separated among two or three TDRSs. Multiple access service allows one forward link per TDRS, which must be shared sequentially by the users. Single access service is available at S-band (SSA) or K-band (KSA) for two users per TDRS. Single access service includes simultaneous forward and return links. Return link data rate limits are 12 Mbps for S-band and 300 Mbps for K-band. Users require as little as 2- to 5-W transmitters and a low gain antenna to transmit about 1 kbps on the MA return, up to about 20 W and a 6-ft diameter steerable antenna to transmit 100 Mbps on the KSA return link.

Figure 7-35 is a picture of a TDRS. The central body is hexagonal, about 8 ft across and 5 ft high. This body and the solar arrays are derived from the FLTSATCOM design. The large antennas with the mesh surface are 16 ft in diameter and are deployed in orbit, being folded like an umbrella during launch. They are used for the single access user links at both S- and K-band. They can be pointed up to 90 deg off nadir away from the satellite or up to 30 deg off nadir toward the satellite body, and rotated ± 90 deg from nadir about the axis that includes their deployment booms. The smaller circular antenna to one side of the satellite body is for the link with the ground terminal. The 30 helix antennas on the face of the satellite form the phased array for the S-band multiple access links with the users.

The irregular antenna to one side of the body and the circular antenna on the face of the satellite are not used by TDRSS. They are part of the Advanced Westar subsystem, which shares the spacecraft with the TDRSS equipment. The Advanced Westar equipment was not removed when that mission was terminated (see below). Figure 7-36 is a block diagram of all the communications equipment on the spacecraft. The portions that are shared and those that are dedicated to the two missions are indicated. The spacecraft

design and the TDRSS mission communication characteristics are summarized in Table 7-21.

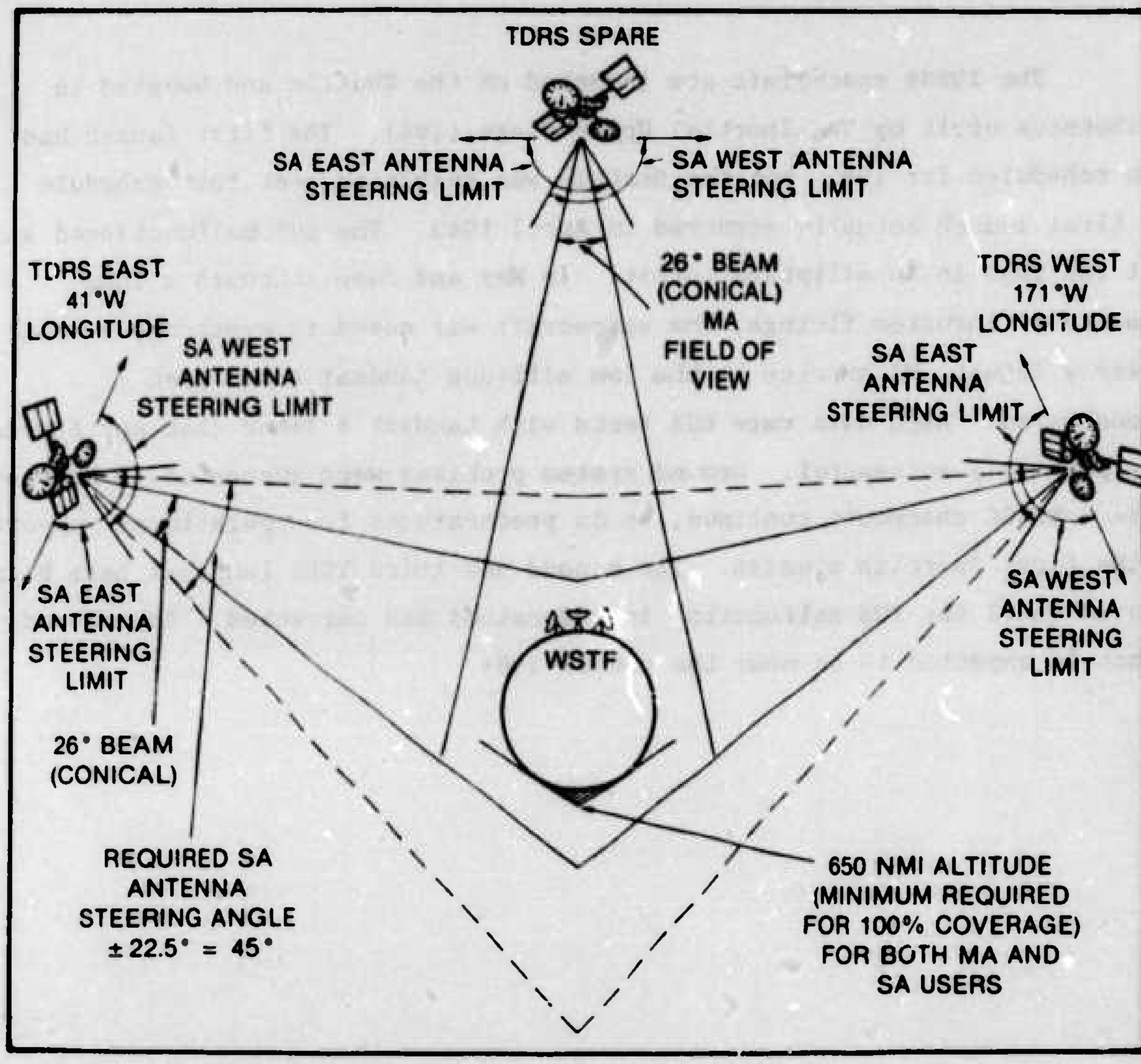
The uplink from the ground terminal to the TDRS is a composite of all forward data and tracking signals and command and control data for the spacecraft. The forward portion of the IF processor demultiplexes this uplink, and the return portion of the processor combines all the return links and the spacecraft telemetry for the composite downlink to the terminal. The downlink uses two polarizations, one for an FDM combination of one KSA link, the two SSA links, the signals from the 30 MA antenna elements, and the TDRS telemetry. The other polarization is for the second KSA return link. To reduce satellite complexity, the phased array beam forming computations and receiver phase shifters, the single access antenna autotracking computations, and the master oscillator for the satellite frequency generator are all in the terminal. The uplink and downlink include all signals necessary for these functions.

The TDRSS ground terminal is located at White Sands, New Mexico, and the building includes all equipment necessary for TDRSS operations as well as space for NASA to install mission peculiar equipment. Three 60-ft antennas handle the uplinks and downlinks for the two active satellites and the spare. The terminal also has antennas for S- and K-band user simulations, an S-band TT&C antenna (used during launch and positioning, and if the K-band TT&C fails), and a K-band TT&C antenna. NASA will provide for communications between the TDRSS terminal and mission control centers, primarily via domestic communication satellites.

The original NASA contract for TDRSS was with Western Union Space Communications. In 1980 the contract was transferred to a partnership of Western Union, Fairchild, and Continental Telephone, called Spacecom. At the end of 1982 the contract was modified to eliminate the Advanced Westar mission. Initially, sharing the spacecraft between two missions seemed to be an economic advantage to both NASA and Western Union. However, as the program progressed, both parties realized they would do better with separat

satellites. (Western Union had already launched the Westar IV and V because of the delay in orbiting the Advanced Westar mission.) Therefore, NASA paid Spacecom an amount of money to gain full control of the satellites. This money compensated Spacecom for the revenues it would have received from use of Advanced Westar. Finally, in January 1983, Western Union sold its share of Spacecom to the other two partners.

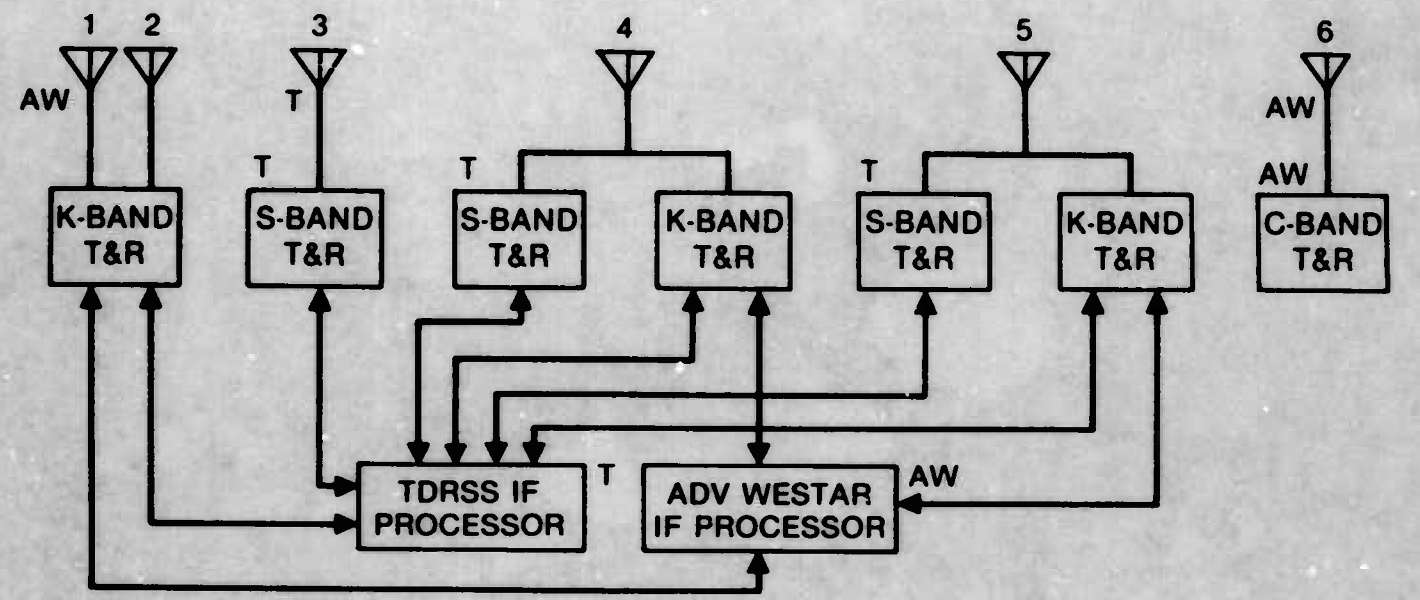
The TDRSS spacecraft are launched on the Shuttle and boosted to synchronous orbit by the Inertial Upper Stage (IUS). The first launch had been scheduled for 1980, but the Shuttle was unable to meet that schedule. The first launch actually occurred in April 1983. The IUS malfunctioned and left the TDRS in an elliptical orbit. In May and June, through a long sequence of thruster firings, the spacecraft was moved to synchronous orbit. By early August, MA service to the low altitude Landsat 4 had been demonstrated. High data rate KSA tests with Landsat 4 later that month were only partially successful. Ground system problems were suspected to be the cause. TDRSS checkouts continue, as do preparations for operational support of the first Spacelab mission. The second and third TDRS launches have been delayed until the IUS malfunction is understood and corrected. The second launch is expected to be near the end of 1984.



NOTE: TDRSS EAST/WEST SA ANTENNA POINTING LIMITS ARE SHOWN. TDRSS NORTH/SOUTH POINTING LIMITS ARE ±90°

Figure 7-34. TDRS System

Figure 7-35. TDRSS Spacecraft



ANTENNAS:

1: BODY-MOUNTED PARABOLA
2 AND 6: DEPLOYED SOLID REFLECTORS
3: 30-ELEMENT PHASED ARRAY
4 AND 5: DEPLOYED MESH REFLECTORS

T: EQUIPMENT USED ONLY BY TDRSS
AW: EQUIPMENT USED ONLY BY ADVANCED WESTAR*
OTHER EQUIPMENT IS USED BY EITHER
T&R: TRANSMITTERS AND RECEIVERS

*Prior to AW cancellation (see text).

Figure 7-36. TDRS Communication Subsystem

Table 7-21. TDRS Details

Satellite	Hexagonal prism body ~8 ft across and 5 ft high, 57 ft between tips of deployed solar arrays, 43 ft across large deployed antennas ~5000 lb in orbit, beginning of life Sun tracking solar array and NiCd batteries, 1700 W end of life 3-axis-stabilized, $\pm 0.1^{\circ}$ in pitch and roll, $\pm 0.25^{\circ}$ in yaw
Configuration	Multiple S-band and K-band transmitters and receivers, all connected to an IF processor
Capacity	S-band multiple access (MA): 1 forward link at 0.1 to 10 kbps, up to 20 simultaneous return links at 0.1 to 50 kbps each S-band single access (SSA): 2 forward links at 0.1 to 300 kbps each, 2 return links at 0.1 kbps to 12 Mbps each K-band single access (KSA): 2 forward links at 1 kbps to 25 Mbps each, 2 return links at 1 kbps to 300 Mbps each Each single access antenna can support 1 forward, and 1 return link at S- or K-band at a time (1 forward and 1 return link at both frequencies simultaneously is possible to a single user or to separate users less than 0.4° apart)
Transmitter[a]	MA: 2103.4 to 2109.4 MHz 35 W total power, 3.5 W each from 10 phased elements (8 required at end of life) 34 dBW ERP SSA: in the band 2025.8 to 2117.9 MHz 15/26-W TWT 44.0/46.4 dBW ERP KSA: in the band 13.75 to 13.8 GHz 1.5-W TWT 49.4 dBW ERP K-band to terminal: 13.4 to 14.05 GHz 18-W TWT for each of 2 links 50.9/52.8 dBW
Receiver[a]	MA: 2285 to 2290 MHz Transistor preamplifier for each of 30 antenna elements -14.1 dB/$^{\circ}$K G/T per element at edge of coverage ~-1 dB/$^{\circ}$K overall G/T (-2 dB/$^{\circ}$K end of life)

Table 7-21. TDRS Details (Continued)

	SSA: in the band 2200 to 2300 MHz Parametric amplifier first stage 8.9 dB/°K G/T KSA: in the band 14.891 to 15.116 GHz Parametric amplifier first stage 24.4 dB/°K G/T K-band from terminal: 14.6 to 15.25 GHz Transistor preamplifier 10.0 dB/°K G/T
Antenna	MA: 30-element phased array (only 10 elements used for transmission), 15.4-dB peak element gain, 13.1-dB gain over 26° field of view, 13.8-dB combining gain (14.8 dB theoretical), 1 transmit beam, up to 20 receive beams can be formed in the 26° field, circularly polarized SSA and KSA: two 16-ft parabolas, 36.7/53.5-dB peak transmit gain, 37.7/54.6-dB peak receive gain, 0.5/0.6-dB pointing loss, 2°/0.28° beamwidth, circular polarization, open loop S-band pointing, autotrack K-band pointing, steerable ±90° N-S and 30/90° E-W (30° toward satellite body, 90° away) K-band terminal link: 6.6-ft parabola, 45.3-dB peak transmit gain, 46.0-dB peak receive gain, 0.7-dB pointing loss, 0.7° beamwidth, linear polarization
Design Life	10 yr
Orbit	Synchronous, ≤7° inclination, E-W stationkeeping to ±0.1°
Orbital History	1: Launched 4 Apr 1983, in use, 41°W longitude 2: Launch scheduled Dec 1984, will go to 171°W longitude 3: Launch scheduled 1985
Developed for	Space Communications Inc. (for lease to NASA)
Developed by	TRW Defense and Space Systems Group
Operated by	Space Communications Inc.

[a]ERP and G/T values are requirements, which were generally exceeded by on-ground measurements.

7.5 UNITED STATES (Direct Broadcast Satellites)

7.5.1 Overview (Refs. 533-537)

The Broadcasting-Satellite Service (BSS) was recognized as a distinct radio service by the International Telecommunications Union (ITU) in 1963. An ITU conference in 1971 allocated several frequency bands to the BSS, and noted a difference between community reception and individual reception. The latter corresponds to what is now called direct broadcast. Reception of a direct broadcast transmission, within a designated service area, requires an antenna not larger than about 3 ft diameter, and a relatively low cost converter-amplifier connected to an existing TV set. This contrasts with more elaborate equipment and antenna diameters of 10 to 33 ft or more, which are currently used to receive TV program transmissions from domestic communication satellites, for distribution to individual homes via cables and other means.

ATS 6, launched in 1974, was the first satellite to demonstrate high power television broadcasting to relatively simple receivers. CTS, launched in 1976, had sufficient power to allow reception with antenna diameters as small as 2 ft. In 1978 Japan launched an experimental broadcasting satellite for a nationwide test. The experimental satellites used various frequencies. All future U. S. broadcasting satellites will use the 17.3 to 17.8 GHz band for uplinks and 12.2 to 12.7 GHz for downlinks.

In 1977 an ITU conference defined direct broadcast system characteristics and assigned satellite locations and frequencies for all countries except those in North and South America. An ITU conference in June and July 1983 did the same for the Americas. The FCC began preparations for the 1983 conference in the summer of 1980. In October of that same year the FCC began a definition, allowing for comments from all interested parties, of direct broadcast system policy. In April 1981 this investigation concluded that such systems are in the public interest and should be allowed to develop with a minimum of regulation. Meanwhile, in December 1980 Satellite Television Corporation (STC), a subsidiary of Comsat Corporation, filed an

application with the FCC for permission to construct a direct broadcast system. The FCC later defined a date in July 1981 by which all applications were required for consideration in the first round of authorizations.

Fourteen applications were submitted by the deadline. The STC application was approved in October 1981. Seven others were approved in November 1981. These seven were from:

a. CBS
b. Direct Broadcast Satellite Corp.
c. Graphic Scanning Corp.
d. RCA Americom
e. United States Satellite Broadcasting Corp.
f. Video Satellite Systems
g. Western Union.

The approvals authorized construction of satellites. However, they are contingent upon the applicants making all modifications necessary to comply with the results of the 1983 ITU conference. Later, another approval will be necessary for system operation. Some basic characteristics of these eight systems are given in Table 7-22. One other application was determined not to require a construction permit. The remaining applications were rejected as incomplete. Some of these applications have been revised and resubmitted. Along with at least two new applications, they are waiting for a second-round consideration by the FCC.

The eight systems differ in many ways. One group of differences is technical characteristics, such as channel bandwidth, satellite output power, polarization, and size of the service area. The majority of these differences were eliminated by the decisions of the ITU conference. The other main group of differences is in programming. Variations include the type of programs, who will provide them, and whether they will be subscriber or advertiser supported. In addition, some of the applicants propose interim, lower-powered, transmissions using various domestic satellites.

In spite of open FCC policy and approvals, there is still a long way to establishing systems. Finances are a big barrier, with estimates of system costs varying between about $200 and $800 million. Furthermore, during the FCC hearings, and even now, there was opposition to direct broadcasting satellites from terrestrial television broadcasters. Like the initial phase of the U. S. domestic satellites a decade ago, the direct broadcast industry will no doubt produce a few satellite launchings in the next five years, but will also have several applicants drop out.

7.5.2 Satellite Television Corporation (Refs. 538-542)

STC is planning a nationwide direct broadcast service. This service will be provided by four active satellites (Figure 7-37), each serving an area approximating a time zone. Each satellite will transmit three television programs. STC satellite details are given in Table 7-23.

The transmitters dominate the satellite design. Each of the three channels has a 200-W TWT, which is the highest power considered reasonable for a long-life satellite. The three TWTs are each expected to require about 500 W of DC power. This requirement, plus the power for other satellite functions, means that the solar array must provide at least 1700 W at end of life. This corresponds to about 2500 W at the start of the seven-year life and is the reason for the large solar array. The transmitters are not operated when the satellite is in an eclipse, because such operation would require very heavy batteries. Rather, the satellites are located so that the eclipse occurs after one a.m. in the service area. The TWT collectors are located outside the satellite body so that the heat generated by their operation can be radiated directly to space.

The large reflector is deployed when the satellite reaches synchronous orbit. It is illuminated by an array of up to 15 feed horns to generate a beam shape approximating the service area. Figure 7-38 is a plot of the eastern service area beam. The transmitter power is divided among the feed horns in a manner to equalize the quality of reception throughout the

service area. Each satellite is equipped with two feed arrays, so that it may serve either the eastern or central service areas, or the mountain or pacific service areas.

The complete communication subsystem consists of a wideband receiver followed by the three transmitters (Figure 7-39). For normal use, each transmitter has a 16-MHz bandwidth. For experiments with high resolution TV transmissions*, two channels have alternate, wider bandwidths.

All of the satellites have a receive beam, which covers the Los Angeles to Las Vegas region. STC is building a broadcast center near Las Vegas where all programming will be coordinated and transmitted to the satellites. The location was chosen for favorable propagation conditions at the 18-GHz uplink frequency and for good visibility to all four satellite locations. This center will also serve as a system control and TT&C facility. Backup equipment for these functions is located at a Comsat General facility in Santa Paula, California.

The programming presented by STC will cover a broad range, including entertainment, sports, children's programs, and education. Since the programming is supported by subscriber fees, all transmissions will be scrambled. Authorized viewers will have a decoder that will unscramble the received signal.

Although the initial contract was for construction of only two satellites, STC has four satellite launches scheduled in 1986. In any case, the first satellite will serve the eastern time zone, and subsequent satellites will expand the service. The final deployment will have two spare satellites in orbit along with the four active satellites.

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*Although several direct broadcast systems plan high resolution experiments, no standards exist.

In the summer of 1983 STC announced plans for an interim service, which could begin in fall 1984. This service will use SBS 4. That satellite is being modified by addition of a switch after one five-channel output multiplexer and addition of diplexers to a few receive antenna feed horns. These modifications allow five channels to be transmitted with high ERP in a beam covering the states from Virginia through Pennsylvania to New Hampshire. The home receivers for this service will be designed to require minimal modification when the STC satellites begin operation.

7.5.3 Other Systems (Ref. 537)

No other satellites have been discussed in detail. No satellite development contracts except STC's have been announced. Besides STC, only RCA has firmly scheduled launches, of which there are five in 1986 through 1988. Thus, it can be inferred that all the other system operators are at least one year behind STC in deploying actual direct broadcast satellites. However, some operators might develop interim systems in a relatively short time using existing or modified domestic satellites.

Table 7-22. Direct Broadcast System Characteristics

Applicant	Satellites[a]	Service Area Size	Channels per Service Area	Satellite Channel Bandwidth[b], MHz	Satellite ERP, dBW[c]	Receiver: Antenna Diameter, in.[b]	Receiver: G/T, dB/°K[b]
CBS	4/1-2	time zone	3	27	60 (peak)	40	12
Direct Broadcast Satellite Corp.	3/1	1-1/3 time zone	6	22.5	56	36	12
Graphic Scanning Corp.	2/1	2 time zones	2	18	54	36	10
RCA Americom	4/2	time zone	4	24	?	24-40	7.2-13.2
Satellite Television Corp.	4/2	time zone	3	16	57	30	9.4
United States Satellite Broadcasting	4/1	time zone	3	16	57	30	8.8
Video Satellite Systems	4	time zone	2	17.5	56	36	10.2
Western Union	4/2	time zone	4	16	55.5 (peak)	36	10.4

[a]Active/Orbital spares for a complete system.
[b]ITU specified values are 24 MHz, 39 in., 10 dB/°K.
[c]At edge of service area unless specified.

Table 7-23. STC Satellite Details

Satellite	Box shaped body 52 x 80 x 44 in., two deployed solar arrays each 6.3 x 17.5 ft; overall span 55 ft. 1430 lb in orbit, beginning of life Solar cells and NiCd batteries, ~2500 W beginning of life, ~1700 W end of life; batteries support only housekeeping functions during eclipse 3-axis stabilization, accuracy $\pm 0.1^{\circ}$ (pitch, roll), $\pm 0.5^{\circ}$ (yaw)
Configuration	Three 16-MHz bandwidth single conversion repeaters (bandwidth may be changed to 24 MHz to comply with ITU conference decisions); may be switched to use two repeaters with 28 or 100 MHz bandwidth for experiments
Transmitter	In 12.2 to 12.7 GHz band One active plus one spare 200-W TWT per repeater ERP 55 to 58 dBW, varying over a service area in proportion to expected path loss; a potential alternate is service to two areas simultaneously with ~3dB lower ERP
Receiver	In 17.3 to 17.8 GHz band One active plus one spare receiver 5.6 dB/$^{\circ}$K G/T
Antenna	One 85-in. diameter paraboloid; two beam forming networks with up to 15 horns each; each satellite has networks for transmissions to either eastern and central time zones or mountain and pacific time zones, pacific zone includes 0.6° spots for Hawaii and Alaska; receive beam covers Los Angeles to Las Vegas area for all satellites; the two networks use opposite circular polarizations
Design Life	7 yr
Orbit	Synchronous equatorial, stationkeeping to $\pm 0.1^{\circ}$N-S and E-W, 115°, 135°, 155° and 175°W longitude were proposed locations; longitudes assigned to U. S. include 110°, 119°, 148°, 157°, 166° and 175°W
Orbital History	Four Shuttle launches scheduled in 1986, two in 1987
Developed for	Satellite Television Corporation
Developed by	RCA Astro Electronics
Operated by	Satellite Television Corporation

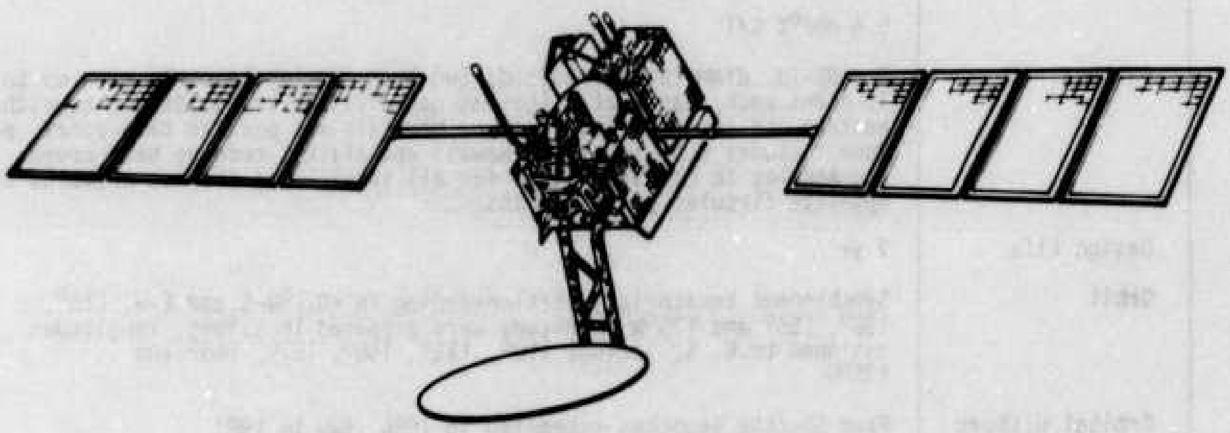


Figure 7-37. STC Satellite

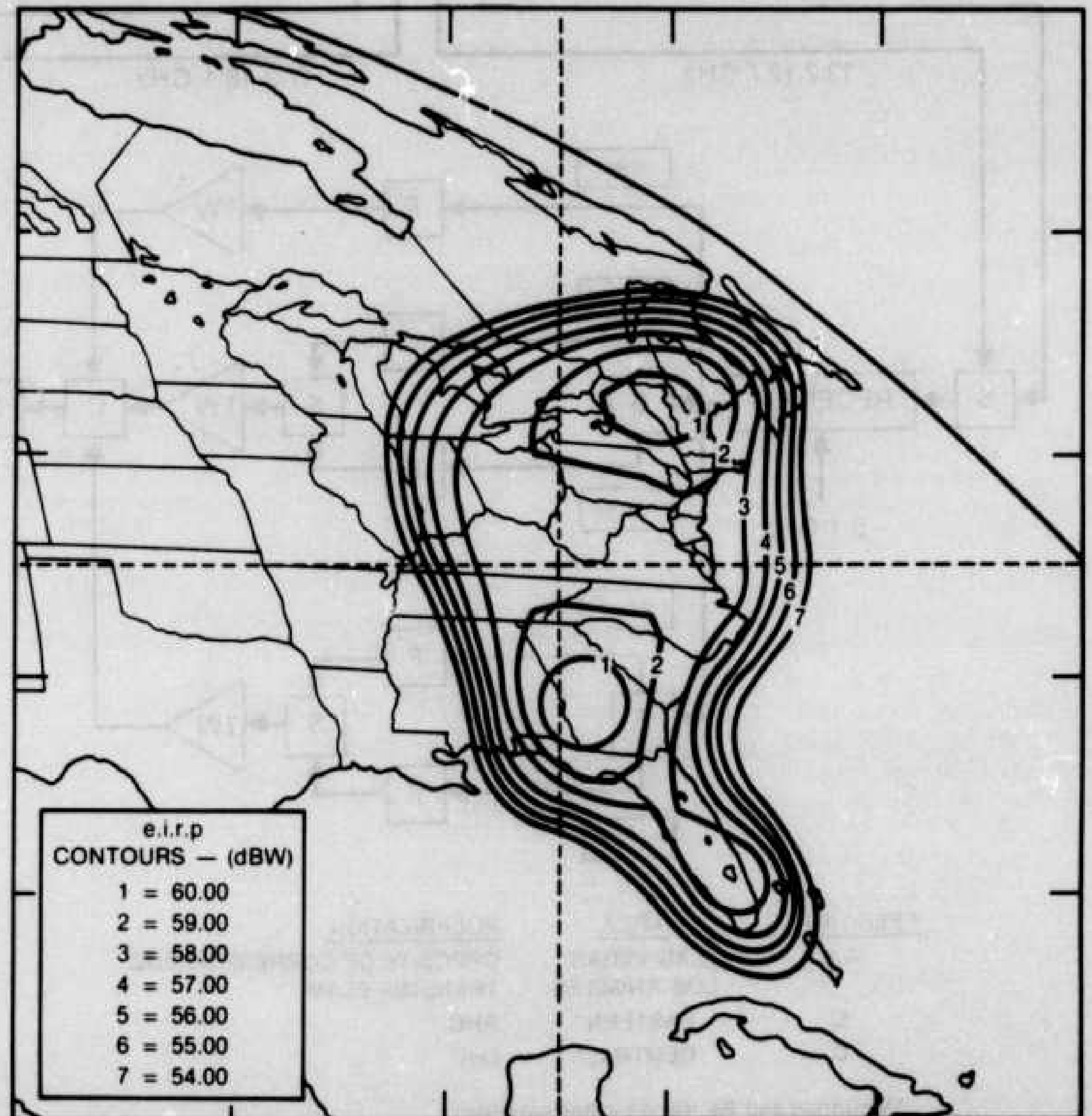
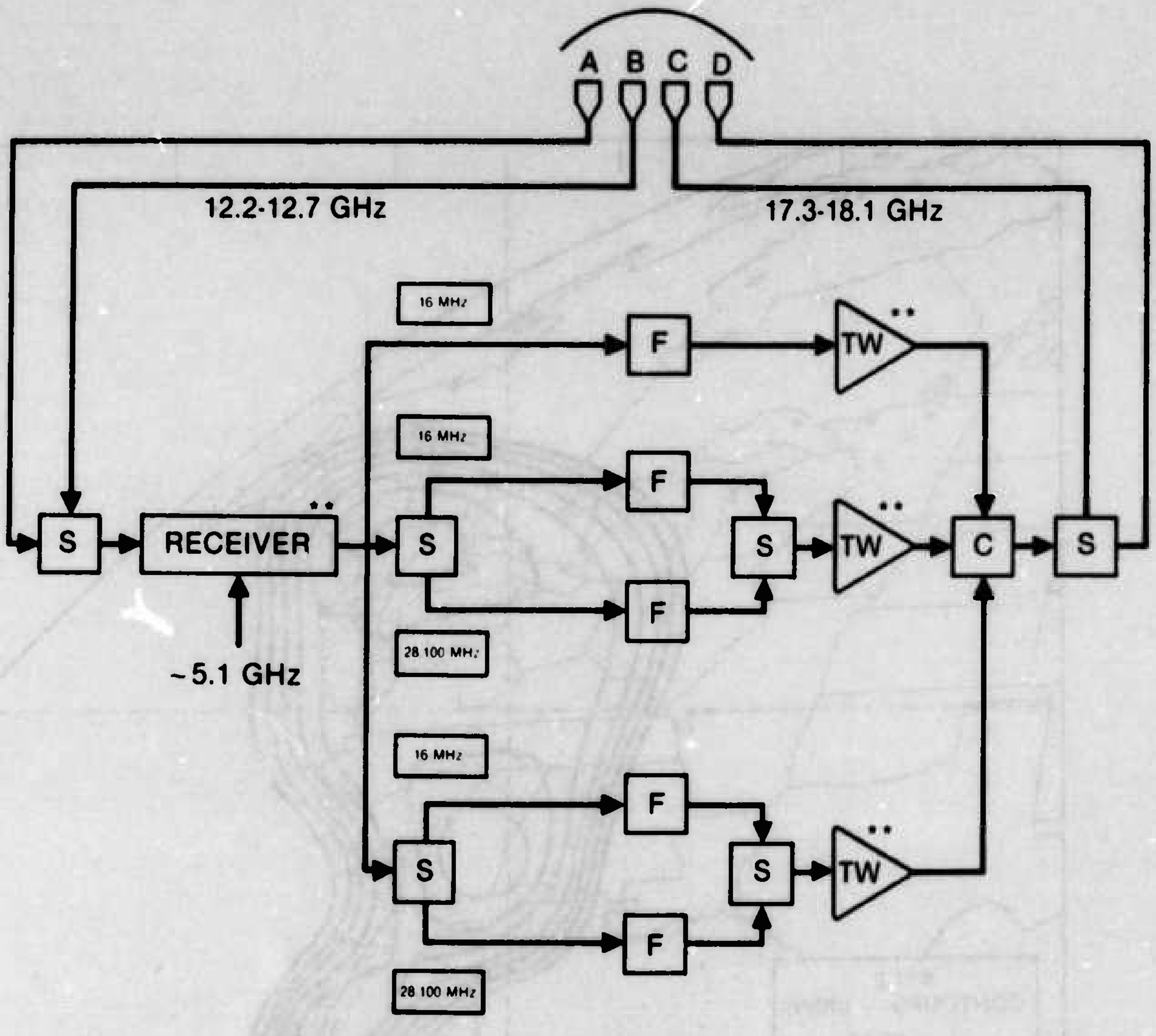


Figure 7-38. STC Eastern Service Area



FEED HORNS	AREA	POLARIZATION
A,B	LAS VEGAS-LOS ANGELES	OPPOSITE OF CORRESPONDING TRANSMIT BEAM
C	EASTERN*	RHC
D	CENTRAL*	LHC

*Mountain and Pacific on other satellites
**Redundant units not shown

Figure 7-39. STC Communication Subsystem

7.6 SYMPHONIE (Refs. 543-551)

The Symphonie program is a joint effort of France and Germany, established in 1967. The primary goals of the program are to gain technical knowledge and experience in the development of communication satellites and to perform transmission experiments. A group of six French and German companies (the CIFAS consortium*) performed the design and development of the satellite.

The satellite has a three-axis-stablized hexagonal body and three solar panels that are deployed in orbit (see Figure 7-40). The solar panels maintain a fixed orientation as they have no mechanism for tracking the sun. The communication subsystem (Figure 7-41) has two 90-MHz bandwidth double conversion channels. Each channel has a tunnel diode preamplifier and a 13-W TWT transmitter. A single earth coverage horn is used for reception. Two elliptical reflectors with off-axis feeds are used for transmission. Each reflector produces an 8 deg x 13 deg beam. One TWT is connected to each transmitting antenna, and a switch allows reversal of these connections. It was planned that the satellites would be stationed over the Atlantic Ocean, with one transmitting antenna covering most of Europe and Africa and the other covering the eastern U. S. and Canada and part of South America. Other details of the Symphonie satellite are given in Table 7-24.

The Symphonie system was planned for two operating satellites in orbit. Transmitting and receiving frequencies of these two satellites are not identical, but interleaved (see Table 7-24) and thus the two satellites can be placed very close to each other in orbit without mutual interference. To ground terminals, they should appear to be almost a single satellite with four channels.

The first Symphonie launch occurred in December 1974, and the second launch was in August 1975. Both satellites have been used for a variety of

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*Consortium Industriel Franco-Allemand pour le satellite Symphonie.

communication links. Original plans indicated that the launches would be from Kourou, French Guiana, using the Europa II launch vehicle. However, since the Europa program was canceled, the Symphonies were launched by the U. S. on a Delta launcher. Initially, both satellites were at 11.5°W longitude. In 1976 the first was moved to 49°E and in that position it was used by several African and Asian countries for experimental programs. A few years later it was returned to approximately 11.5°W, where both satellites are at present.

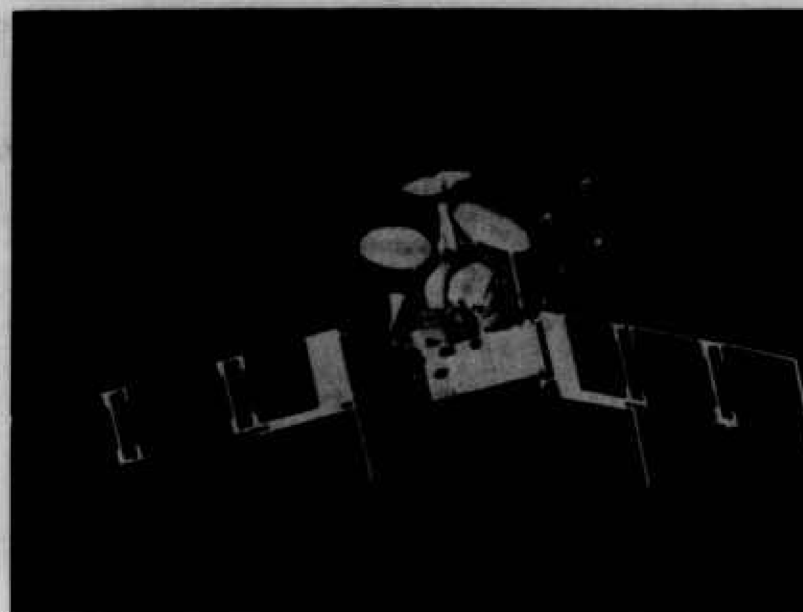
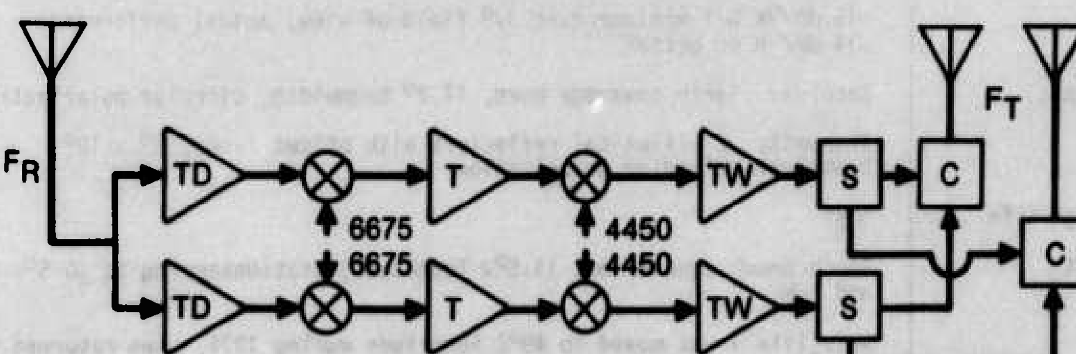


Figure 7-40. Symphonie Satellite



	SATELLITE 1	SATELLITE 2
RECEIVE FREQUENCIES (F_R):	6065-6155 6320-6410	5940-6030 6195-6285
TRANSMIT FREQUENCIES (F_T):	3840-3930 4095-4185	3715-3805 3970-4060

Figure 7-41. Symphonie Communication Subsystem

Table 7-24. Symphonie Details

Satellite	Hexagonal body, 68-in. maximum diameter, 20 in. high, 23-ft diameter with solar panels deployed
	538 lb in orbit, beginning of life
	Solar cells and NiCd batteries, 300 W initially, 180 W minimum after 5 yr (batteries do not support the communication subsystem during eclipse)
	3-axis stabilization, 0.5^{o} attitude control accuracy
Configuration	Two 90-MHz bandwidth double conversion repeaters
Capacity	600 one-way voice circuits or 1 color TV signal with 3 voice channels per repeater
Transmitter	3715 to 3805 and 3970 to 4060 MHz (satellite 2)
	3840 to 3930 and 4095 to 4185 MHz (satellite 1)
	13-W TWT per channel (no redundancy)
	29-dBW minimum ERP per channel over $8^{o} \times 13^{o}$ field of view, 30 dBW typical
Receiver	5940 to 6030 and 6195 to 6285 MHz (satellite 2)
	6065 to 6155 and 6320 to 6410 MHz (satellite 1)
	Tunnel diode preamplifier
	~7.5 dB noise figure
	-15 dB/^{o}K G/T minimum over 17^{o} field of view, actual performance -14 dB/^{o}K or better
Antenna	Receive: Earth coverage horn, 17.2^{o} beamwidth, circular polarization
	Transmit: 2 elliptical reflectors with offset feeds, $8^{o} \times 13^{o}$ beamwidth, circular polarization
Design Life	5 yr
Orbit	Synchronous equatorial, 11.5^{o}W longitude; stationkeeping to $\pm 0.5^{o}$N-S and E-W
	Satellite 1 was moved to 49^{o}E longitude during 1976, then returned to 11.5^{o}W
Orbital History	1: Launched 18 Dec 1974, in use as of mid 1983
	2: Launched 27 Aug 1975, in use as of mid 1983
	Delta 2914 launch vehicle
Developed for	Centre National d'Etudes Spatiales (CNES) - French Space Agency
	Deutsche Forschungs und Versuchsanstalt für Luft und Raumfahrt (DFVLR) - German Space Agency
Developed by	CIFAS - a French-German industrial consortium

7.7 EUROPEAN SPACE AGENCY (Refs. 552-561)

The European Space Agency (ESA) was formed in May 1975 by a merger of the European Space Research Organization (ESRO) and the European Launcher Development Organization. ESA has eleven member nations and two nations with "observer" status. All the nations do not participate in every program, but most programs are supported by at least eight nations. Each nation's contributions to an ESA program may vary from about one to 60 percent of the total program cost, with Great Britain, West Germany, and France being the largest contributors. It is normal for the contracted work on each project to be distributed among the countries in proportions closely matched to their contributions. This results in more complicated industrial teaming arrangements than exist in the U. S., which leads to greater management complexity and higher overhead costs.*

The ESA has several communication satellite projects. The first is the Orbital Test Satellite (OTS), which is a preoperational test for a Eurpoean regional communication system. The operational satellites are called the European Communication Satellite (ECS) series. Marecs is a derivative of ECS and is designed for communication with ships. The Large Satellite is a newer program aimed at developing a spacecraft that is about double the size of the OTS. Each of these satellites is described below. European satellites that are not ESA projects are described in the following sections of this report.

7.7.1 OTS (Refs. 562-585)

The OTS is a part of the European Communication Satellite Program. The primary aim of the overall program is to "make available to European post and telecommunications authorities satellite links for a significant portion of the intra-European telephone, telegraphy, and telex traffic in the 1980s, as well as to satisfy the requirements of the European Broadcasting Union

*See Ref. 553 for a more complete discussion of this subject.

(EBU) for Eurovision relay." The program had three phases leading to an operational system. Phase 1 (1970-1971) included system studies and initial technology development. Phase 2 (1972-1977) included additional technology development, communication system definition, and the development and launch of OTS. Phase 3 (1977-1980) was the procurement and launch of operational satellites. (Since the plan was formulated, Phase 2 slipped about 1 year and Phase 3 about 2 years.)

OTS is basically experimental in nature, but is being designed with a configuration similar to that expected for the operational satellites. The objectives of the OTS program are to:

a. Demonstrate the performance and reliability of the satellite subsystems.

b. Demonstrate the proposed operational capabilities and provide the capacity for preoperational transmissions.

c. Gain experience in communication satellite system operations.

d. Perform propagation measurements at 11 and 14 GHz.

OTS is a three-axis-stabilized satellite with two solar arrays that deploy after synchronous orbit has been achieved (see Figure 7-42). The solar arrays rotate about their axis to track the sun. The main body of the satellite is a hexagonal prism with a maximum diameter of about 7 ft. The six communications antennas are mounted on the earth-viewing end of the satellite body. Table 7-25 is a summary of OTS characteristics.

The OTS communication subsystem has characteristics identical to those planned for operational satellites, except for a reduced number of channels. During the time of the OTS design, the operational satellites were expected to have six 40-MHz and six 120-MHz channels grouped in pairs with the two channels of each pair sharing the same frequencies by means of orthogonal polarizations. OTS has one pair of 40-MHz channels and one pair of 120-MHz channels. In addition, there is a dual 5-MHz beacon channel. Figure 7-43 is a block diagram of the communications and beacon subsystems.

The communication channels use orthogonal linear polarizations with redundant dual-polarization receiving antennas. These antennas are connected to redundant wideband receivers that have parametric amplifier front ends. After the receivers, the four channels are separated and each passes through separate filters, IF amplifiers, upconverters, and 20-W TWTs. The two 40-MHz channels are transmitted by a single antenna that radiates dual orthogonal linear polarizations. The 120-MHz channels share a single dual-polarization antenna that has a narrower beamwidth.

The beacon transponder has separate receiving and transmitting antennas, each accommodating both orthogonal circular polarizations. The transponder has two complete parallel sets of equipment that can be operated simultaneously, with each channel associated with one polarization. The transponder also generates and transmits an unmodulated beacon at a frequency below the 5-MHz repeater band.

The 40- and 120-MHz channels are both used for telephony transmissions with quadraphase shift keying (QPSK) modulation and TDMA. The 40-MHz channels will also be used for frequency modulated television signals. The receiving antennas for all of these channels and the transmitting antenna for the 40-MHz channels have beamwidths covering all of Europe plus a portion of North Africa. This is the Eurobeam A coverage indicated in Figure 7-44. This coverage is required because the EBU must serve points as widely separated as Iceland, the Azores, and Israel. The 120-MHz channels use a spot beam transmitting antenna with a 2.5 deg beamwidth, which includes the terminals handling about 85 percent of the telephony traffic. The beacon channel uses antennas with an intermediate beamwidth (Eurobeam B in Figure 7-44). This channel is used for propagation measurements and experimental transmissions by small terminals (e.g., an antenna diameter of ~10 ft). More than 30 ground terminal sites (generally only one per country) expected in the operational system are indicated in Figure 7-44; a few were built in time to participate in OTS testing.

When the final design of OTS was started in 1974, the satellite was sized for a Delta 2914 launch vehicle. Later it was redesigned to take advantage of the larger capacity of the Delta 3914. In the payload, the redesign consisted of the addition of the extra TWTs in the wideband channels and the addition of the second beacon channel. The first launch, in September 1977, was unsuccessful because the launch vehicle exploded shortly after liftoff. A spare satellite was successfully launched in May 1978. This satellite was still in use in summer 1983 even though it was two years beyond its design life. Propellant supply is the life-limiting factor; the current estimate is that OTS use will cease in 1984.

7.7.2 Marecs (Refs. 150, 563, 586-603)

The Marots (Maritime Orbital Test Satellite) program was approved in 1973. Its goals were to obtain experimental data and preoperational experience in the maritime satellite environment. The program included communications tests and evaluation of operational techniques and ship terminals of various designs. The basic characteristics of the system were consistent with the available guidelines for future operational systems.

The Marots satellite design was based on the OTS design and the two satellite developments overlapped in several aspects such as personnel, components, and testing. The Marots mission was basically experimental; however, during its development international discussions were proceeding on the deployment of an operational, global maritime system. In 1976 ESA offered Marots for use as part of an interim global system. As a result of many discussions with potential major participants in an international system, several changes were made in the Marots design. These changes caused a significant delay in the development program and, as a result, ESA decided to switch from an OTS-type spacecraft to the more capable Eurpoean Communication Satellite (ECS) spacecraft. Therefore, the name of the satellite was changed to Marecs (Maritime European Communication Satellite). Figure 7-45 is an illustration of Marecs, and the satellite details are given in Table 7-26.

The communication subsystem of Marecs (Figure 7-46) has three channels. The forward channel (shore-to-ship) has a 5-MHz bandwidth and the return channel has a 6-MHz bandwidth. A shore-to-shore channel for network coordination has a 0.5-MHz bandwidth. All links with ships will use L-band, and all links with shore stations will use 4 and 6 GHz. The return channel will provide up to 50 voice channels at all times. The forward channel will handle up to about 40 voice channels depending on the ship terminal G/T, except during eclipse when the capacity is less than 10 channels. All amplifiers are operated in a near linear state so that FDMA operation can be used with acceptable intermodulation levels.

The Marecs development program included two flight model satellites. ESA added a production program in 1978 with an additional flight model. Discussions on the role of Marecs in the Inmarsat system continued from about 1978 to 1981 when Inmarsat decided to include two Marecs in its first generation space segment. Marecs A was launched in December 1981 and went through testing until it was switched into the Inmarsat system in February 1982. Marecs B was lost in a launch vehicle failure in September 1982. It will be replaced by Marecs B2, which will be launched in the first half of 1984.

7.7.3 European Communication Satellite (Refs. 567, 569-571, 577, 604-615)

The European Communication Satellite (ECS) is an operational satellite based on the OTS technology. Although Europe has well-developed terrestrial communications facilities, a satellite system will be useful to help handle increased traffic, provide an alternate path for critical services, and improve communications (especially television distribution) with noncontinental points such as the Azores. The satellite capacity requirements were derived from studies of European traffic levels in the 1980-1990 decade. The satellite system has been sized to accommodate about half of all transmissions between points separated by more than 800 km.

The OTS/ECS program began in the early 1970s with the development of a baseline design for ECS. The purpose of the study was to determine what technology should be tested on the OTS for ECS. Since then the ECS design has been reconsidered several times; the present design uses 80-MHz bandwidth transponders rather than the 40- and 120-MHz combination used in OTS. Also ECS has three spotbeams rather than the one used on OTS. However, even with these design differences, all OTS developments are applicable to ECS.

ECS is a three-axis-stabilized satellite with sun-tracking solar arrays. It is composed of a service module and a communication module, shown separated in Figure 7-47. The communication module includes the earth-viewing, north, and south faces of the body. The antennas are all fixed on the exterior of the earth-viewing face. Communications equipment is attached to the interior of all three faces, with thermal radiators on the exterior of the north and south faces. The service module includes the other three faces and the interior structure. All support equipment is mounted on them. The solar arrays are also attached to the service module.

The satellite is sized for one-half the Ariane launch capability. Because of this limit, the power subsystem can only support nine of the communication subsystem channels. Also, there is no north-south stationkeeping, which means that all ground antennas must have a tracking capability. Satellite details are provided in Table 7-27.

The basic communication subsystem design has twelve channels. Each polarization has six channels with 83.3 MHz center-to-center spacing, which fills the 500-MHz allocation at 11 GHz (downlink) and 14 GHz (uplink). Beginning with the second ECS, an additional pair of downlink channels was added at 12.5 GHz for business services, also called satellite multiservices. One pair of uplink channels may be switched between these additional downlink channels and two of the basic downlink channels. These connections may be seen in Figure 7-48.

ECS has four antenna patterns (Figure 7-49). The Eurobeam is used for both reception and transmission, and covers the entire area which ECS must serve. The three spot beams are for transmission only. The two business services channels have a receive and transmit beam pattern slightly smaller than the dashed ellipse in Figure 7-49. Five of the twelve basic channels are permanently connected to spot beams. The other seven are each switchable between two transmit antennas. The largest number of channels may be connected to the west spot, which covers the cities that account for about 80 percent of the telephony traffic.

The ECS system is operated by Eutelsat, a commercial organization formed by an intergovernmental agreement. Interim Eutelsat was formed in 1977 to prepare for use of the ECS system. A permanent organization was established in 1982. ESA handles all satellite construction and launching for Eutelsat. The first two satellites were ordered in 1979, and the next three in 1980. The first satellite was launched in June 1983 and is in use. The second will be launched in 1984. The others will be ready for launch in 1985 and 1986. Actual launch dates will depend on Eutelsat's needs.

The ECS system was planned with one active and one spare satellite in orbit. The active satellite will support television distribution on one or two channels and trunk telephony on the remaining channels. Transmission methods are FM for television with multiple digital audio channels, and TDM/QPSK/TDMA for telephony. The telephony transmission rate will be 120 Mbps. Digital speech interpolation may be used.

At the end of 1980 a decision was made to add the two business services channels to the ECS design. These will support multiple digital links and rates between 64 kbps and 2 Mbps. The transmission method is SCPC/FDMA. The basic channels interconnect large ground terminals (antenna diameters 35 to 60 ft), typically one per nation, operated by each nation's telecommunications agency. The business services channels will interconnect small ground terminals (antenna diameters ~12 to 20 ft) at many sites within the coverage area. This service will be used by corporations for voice, data,

facsimile, and video conferencing in the same manner as U. S. corporations use the U. S. domestic satellites. Eutelsat is also leasing one channel on the French Telecom 1 satellite for business services.

In 1982 Eutelsat decided to lease excess capacity, primarily on the spare satellite, to national telecommunications agencies for domestic use. Ten channels were offered and about 30 requests were received. Based on this demand, Eutelsat is considering using three satellites in orbit to provide additional capacity.

7.7.4 Large Telecommunications Satellite (Refs. 100, 612, 616-627)

The Large Telecommunications Satellite, or L-Sat, program is the result of a development effort defined in 1976. Former program names include Heavy Telecommunications Satellite, H-Sat, and Phebus. Recently L-Sat has also been called Olympus. The use of "large" or "heavy" in the program name is because the satellite will be about twice the size of ECS. The program direction was guided by several studies of future communication satellite needs, and how European industry could respond to the opportunities to satisfy these needs. The goals of the program are to:

a Develop and demonstrate a large satellite platform.

b. Develop communications hardware for and provide an orbital demonstration of several new communications services.

The L-Sat spacecraft is designed to be adaptible to a variety of payloads within the following payload limits: 7 kW power demand in sunlight, 3 kW in eclipse, 1100 lb including antennas. In addition, the spacecraft must be able to provide adequate space for payload mounting (especially multiple antennas) and thermal radiators. Another L-Sat requirement is compatibility with both Ariane and Shuttle launches. L-Sat will be launched in 1986.

The L-Sat design is shown in Figure 7-50. Future uses of the spacecraft will look the same except for a new set of antennas and a possible change in solar array length. The north and south panels of the spacecraft primarily support payload equipment on the inside and thermal radiators on the outside. The east, west, and back (i.e., anti-earth side) panels, together with a central cylinder which is the primary structure, support propulsion, power, TT&C, and control subsystems. Deployable antennas are mounted on the east and west panels. Other antennas, as well as the remaining payload hardware, are mounted on the earth-viewing face. The solar cells are mounted on a flexible blanket; the arrays are deployed in orbit using a telescoping mast. The propulsion subsystem is a liquid bipropellant type and is used for both the apogee maneuver and on-orbit control. Spacecraft and payload details are given in Table 7-28.

L-Sat has four payloads. The television broadcast payload (Figure 7-51) has two channels, each connected to a separate, steerable transmit antenna. One channel will be used primarily for preoperational direct to home broadcasting in Italy. The other will be used for direct to home broadcasting experiments, and is available to European nations on a time-shared basis. It can also be used for broadcasting multilingual programs to all of Europe for reception by larger terminals. The second channel has a choice of two frequencies and two polarizations for flexibility in matching TV broadcast system characteristics specified for each nation at a 1977 ITU conference. The first channel has characteristics matching the specifications for Italy.

The payload has three antennas, one for reception and two for transmission. The Italian transmit antenna has circuitry for deriving antenna pointing information by tracking a ground-based beacon. The payload has redundant wideband receivers and redundant transmitters, with 230 W helix type TWTs, for each channel.

The business services payload (Figure 7-52), or specialized services payload, will demonstrate concepts for transmission of digital data between small terminals (e.g., 10-ft antennas) at many sites. The downlink is at

12 GHz; the uplink may be either 13 or 14 GHz and is accomodated by switching the local oscillator in the satellite. A single antenna fed by five horns generates five adjacent beams which together cover most of Europe. Frequency reuse will be demonstrated in two pairs of spatially separated beams. The communications equipment has four channels. Input and output switches can form many one-to-one connections between these channels and the receive and transmit beams. In addition, in the central section of the channels, at an intermediate frequency of 825 MHz, is a TDMA switch matrix which can change receiver to transmitter connections many times per second. This switch can connect a receiver to one or several transmitters. Payload demonstrations are expected to use QPSK transmissions with a 25-Mbps TDMA rate.

The 20/30-GHz communications payload (Figure 7-53) has two antennas, each of which may be steered toward any point in Europe. The electronics support two channels. The two will be transmitted through separate antennas; reception may use either or both antennas. The payload has redundant receivers and three transmitters. The payload will be used for both data and video transmissions, to demonstrate satellite hardware and system operation in the 20- and 30-GHz frequency bands. These bands have more spectrum allocated to space communications than the 4/6-GHz and 12/14-GHz bands combined. Thus, they will gradually come into use over the next decade as the demand for satellite capacity continues to increase. A disadvantage is that the propagation impairments caused by rain increase with frequency.

Because of this problem, L-Sat has a 20/30-GHz propagation payload (Figure 7-53). The output of an onboard frequency source is multiplied to produce frequencies at about 20 and 30 GHz. Thses are transmitted through antennas whose beams cover all of Europe for use in propagation measurements. The transmitted signals are not modulated. From the same frequency source a 12.5-GHz beacon is derived. This is transmitted on an earth coverage beam and is intended both for use in propagation measurements and as a tracking beacon for all L-Sat ground terminals.

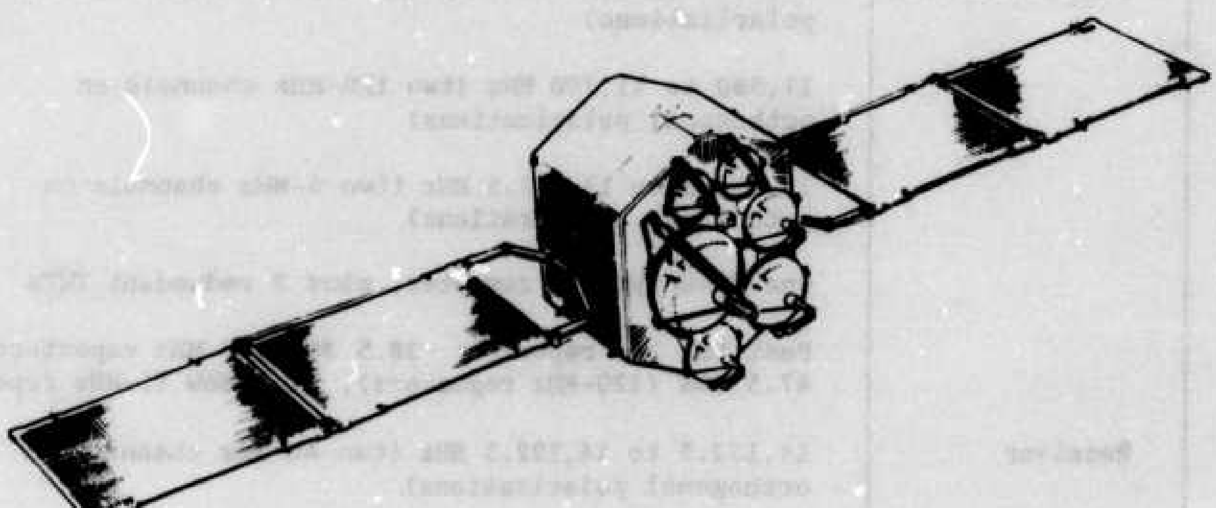


Figure 7-42. OTS Satellite

Table 7-25. OTS Details

Satellite	Hexagonal prism body, 85-in. diameter, 77 in. high, 28.3 ft tip to tip of deployed solar arrays 955 lb in orbit, beginning of life Sun-tracking solar array and NiCd batteries, 750 W initially, 600 W after 3 yr 3-axis stabilization, $\pm 0.17^{\circ}$ (pitch and roll), $\pm 0.5^{\circ}$ (yaw), 3σ, nominal 0.2° antenna pointing accuracy
Configuration	6 double conversion repeaters (two 40 MHz, two 120 MHz, two 5 MHz), dual polarization frequency reuse
Transmitter	11,490 to 11,530 MHz (two 40-MHz channels on orthogonal polarizations) 11,580 to 11,700 MHz (two 120-MHz channels on orthogonal polarizations) 11,792.5 to 11,797.5 MHz (two 5-MHz channels on orthogonal polarizations) One 20-W TWT per repeater, plus 2 redundant TWTs Peak ERP per repeater: 38.5 dBW (40-MHz repeaters), 47.5 dBW (120-MHz repeaters), 41.1 dBW (5-MHz repeater)
Receiver	14,152.5 to 14,192.5 MHz (two 40-MHz channels on orthogonal polarizations) 14,242.5 to 14,362.5 MHz (two 120-MHz channels on orthogonal polarizations) 14,455 to 14,460 MHz (two 5-MHz channels on orthogonal polarizations) 2 receivers (1 on, 1 standby) per polarization (40- and 120-MHz channels) 1 receiver per polarization (5-MHz channels) Parametric amplifier 1000° K system noise temperature

Table 7-25. OTS Details (Continued)

	Peak G /T: -3.6 dB/°K (40- and 120-MHz channels), -1.0 dB/°K (5-MHz channels)
Antenna	3 Eurobeam A (2 receive, 1 transmit), 4.25° x 7.5° at -3 dB contour, ~26.5 dB peak gain, linear polarization 2 Eurobeam B (1 receive, 1 transmit), 3.5° x 5° at -3 dB contour, ~29.1 dB peak gain, circular polarization 1 spot beam (transmit), 2.5° at -3 dB contour, ~35.5 dB peak gain, linear polarization (Gains are measured at input to receive filter or output of transmit filter)
Design Life	3 yr
Orbit	Synchronous equatorial, was 10°E longitude, moved to 5°E longitude in 1982, stationkeeping to ±0.1°N-S and E-W
Orbital History	1: Launch vehicle failure 13 Sep 1977 2: Launched 11 May 1978, in use of as of Aug 1983 Delta 3914 launch vehicle
Developed for	ESA
Developed by	Hawker Siddeley Dynamics (now British Aerospace Dynamics Group), prime contractor for the MESH[a] consortium
Operated by	ESA

[a]A West European industrial consortium.

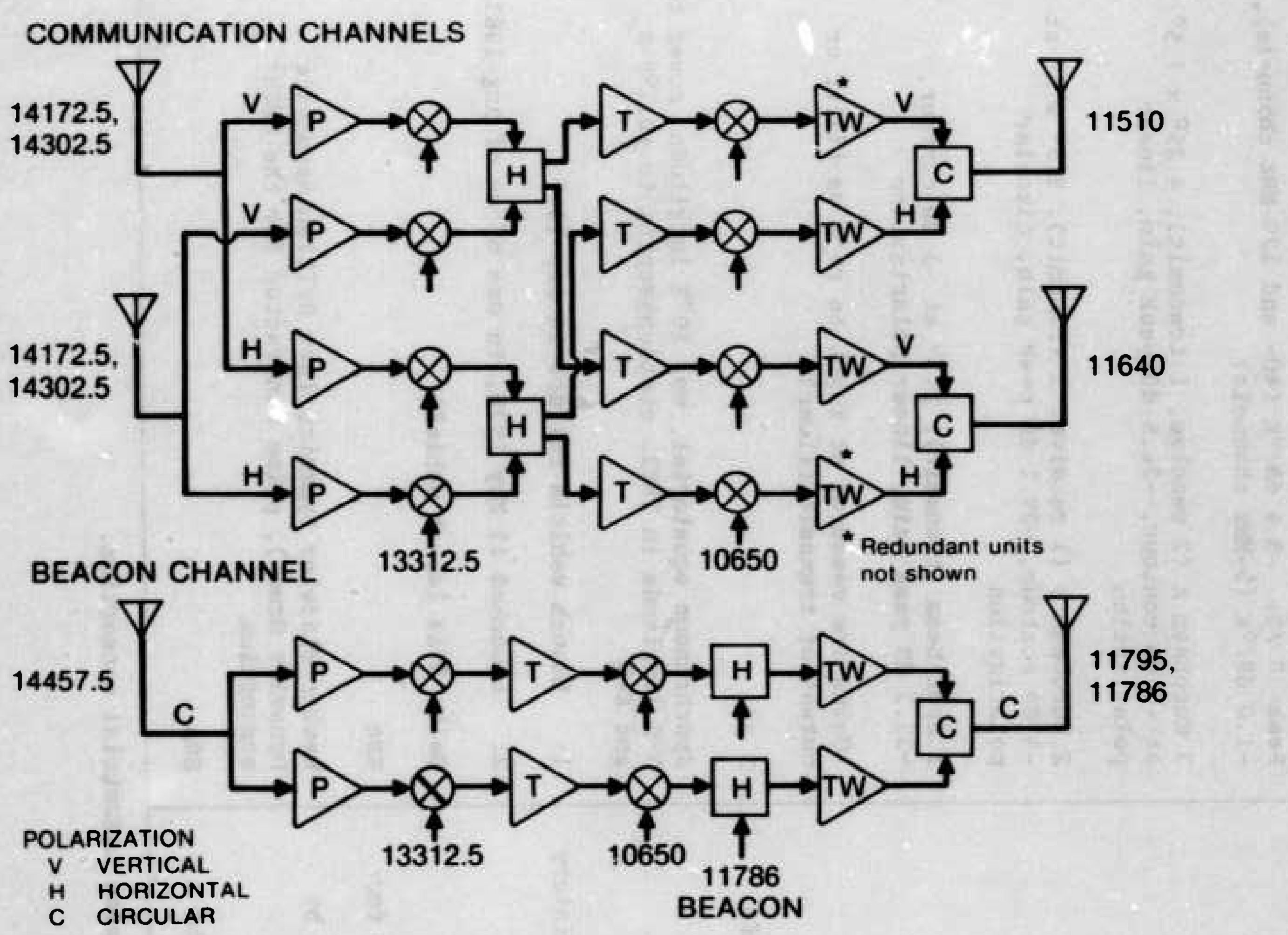


Figure 7-43. OTS Communication Subsystem

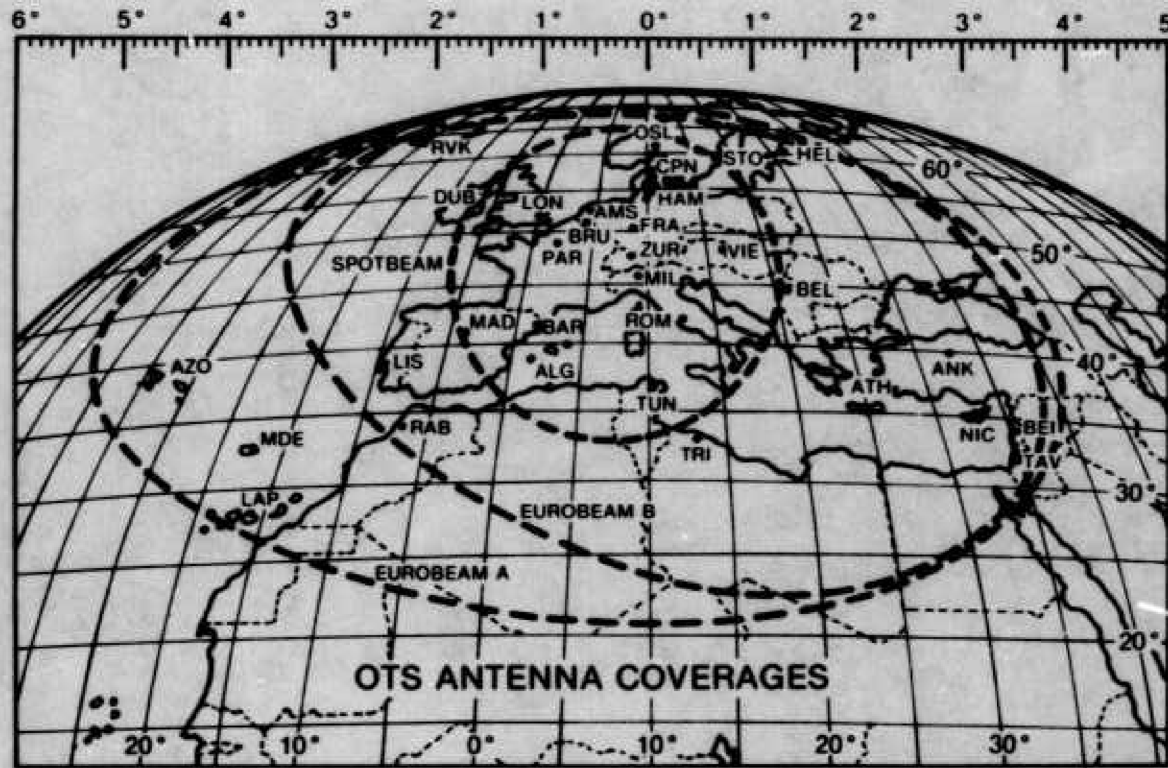


Figure 7-44. European Ground Terminal Sites

Figure 7-45. Marecs Satellite

Table 7-26. Marecs Details

Satellite	Hexagonal prism body, 86-in. diameter, 77 in. high; 45 ft tip to tip of deployed solar arrays, overall height ~100 in.
	1260 lb in orbit, beginning of life
	Sun-tracking solar array and NiCd batteries, 955 W beginning of life, 790 W end of life
	3-axis stabilization, antenna pointing accuracy $\pm 0.2^\circ$ (pitch and roll), $\pm 0.35^\circ$ (yaw)
Configuration	3 repeaters: 4.75-MHz bandwidth for shore-to-ship, 5.9-MHz bandwidth for ship-to-shore, 0.5-MHz for shore-to-shore
Capacity	35 voice channels each direction plus search-and-rescue channel in ship-to-shore direction
Transmitter	4194.6 to 4200.5 MHz (to shore), 1-W TWT plus spare, 14.5 dBW ERP
	1537.75 to 1542.5 MHz (to ships); ten transistor amplifiers available, up to six can be on, maximum output 75 W; maximum ERP at edge of coverage is 34.2 dBW
Receiver	6420.25 to 6425 MHz (from shore), G/T -17 dB/$^\circ$K
	1638.6 to 1644.5 MHz (from ships), G/T -12 dB/$^\circ$K
Antenna	1 L-band (1500 to 1700 MHz) parabolic antenna, 80-in. diameter, beam shaped to give 1.4 dB more gain at edge of coverage than on axis
	2 horns (1 transmit, 1 receive) for 4 and 6 GHz
	All antennas are earth coverage
Design Life	7 yr
Orbit	Synchronous equatorial (inclination <3°), stationkeeping to $\pm 0.2^\circ$E-W
Orbital History	1:[a] Launched 20 Dec 1981, 26°W longitude, in use
	2:[a] Launch failure Sep 1982
	3:[a] Launch scheduled Sep or Nov 1984, will go to 177.5°W longitude
	Ariane launch vehicle
Developed for	ESA
Developed by	MESH consortium (prime contractor, Hawker-Siddeley Dynamics, now British Aerospace Dynamics Group)
Operated by	ESA for Inmarsat

[a]Prelaunch designations are A, B, B2.

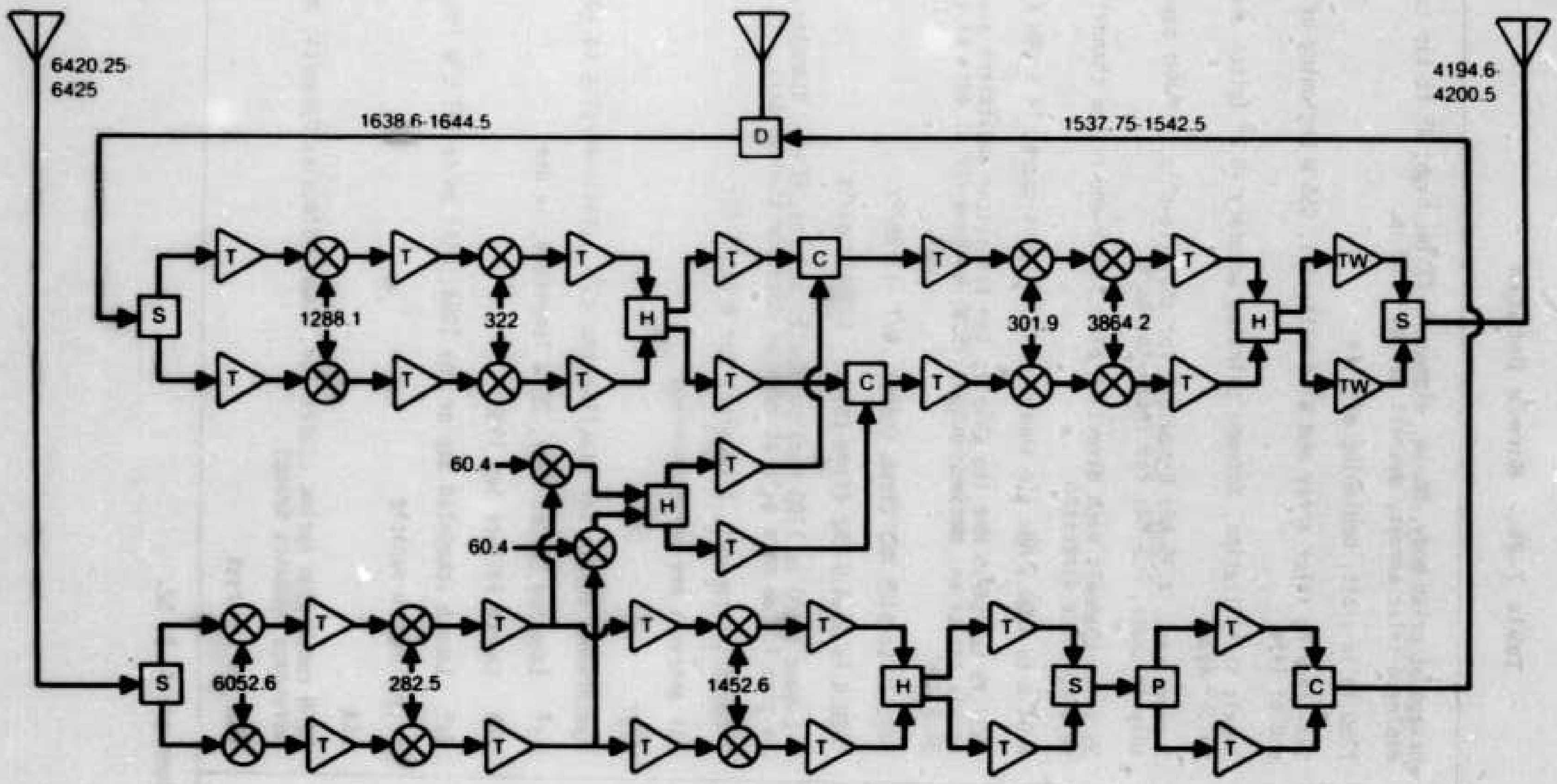


Figure 7-46. Marecs Communication Subsystem

Table 7-27. ECS Details

Satellite	Main body maximum diameter 7 ft, deployed solar arrays span 45 ft 1342[a]/1496[b] lb in orbit, beginning of life Solar cells and NiCd batteries, 900 W minimum at end of life 3-axis stabilization, 0.2° antenna pointing accuracy
Configuration	Twelve 72-MHz bandwidth receive channels, twelve[a]/ fourteen[b] transmit channels, double conversion, solar array can power a maximum of 9 channels, batteries can power a maximum of 5[a]/9[b] channels during eclipse; dual polarization frequency reuse
Capacity	1600 telephone calls (120 Mbps TDMA rate), or 1 TV signal with multiple audio channels, or 400 64 kbps links to small terminals per channel
Transmitter	10.95 to 11.20 and 11.45 to 11.70 GHz (primary services) 12.50 to 12.58 GHz (business services[c]) One 20-W TWT per channel (no spares) ERP at edge of coverage: 34.8 dBW (Eurobeam), 40.8 dBW (spot beams), 39.8 dBW (business service beam)
Receiver	14.0 to 14.5 GHz G/T at edge of coverage: -5.3 dB/°K (Eurobeam), -2.2 dB/°K (business service beam)
Antenna	3 24-in. diameter parabolas each producing one 3.7° transmit spot beam; 1 17-in. diameter parabola[a]/1 offset fed toroidal reflector[b] producing a 5.2° x 8.9° transmit Eurobeam; 2 13-in. diameter parabola[a]/2 offset fed toroidal reflectors[b] producing two 5.2° x 8.9° receive Eurobeams[a]/one receive Eurobeam and one diplexed business services beam[b]; all antennas support orthogonal linear polarizations with 23 dB cross polarization isolation
Design Life	7 yr
Orbit	Synchronous equatorial, inclination ≤3.5°, E-W stationkeeping to ±0.1°
Orbital History	1: Launched 16 Jun 1983, 10°E longitude, in use 2: Launch scheduled May or Jul 1984, will go to 13°E longitude 3: Launch scheduled Aug 1985 4 and 5: Ready for launch in 1986 Ariane launch vehicle
Developed for	ESA acting for Eutelsat
Developed by	The MESH consortium, prime contractor British Aerospace Dynamics
Operated by	Eutelsat

[a]ECS 1
[b]ECS 2-5
[c]Also called satellite multiservices

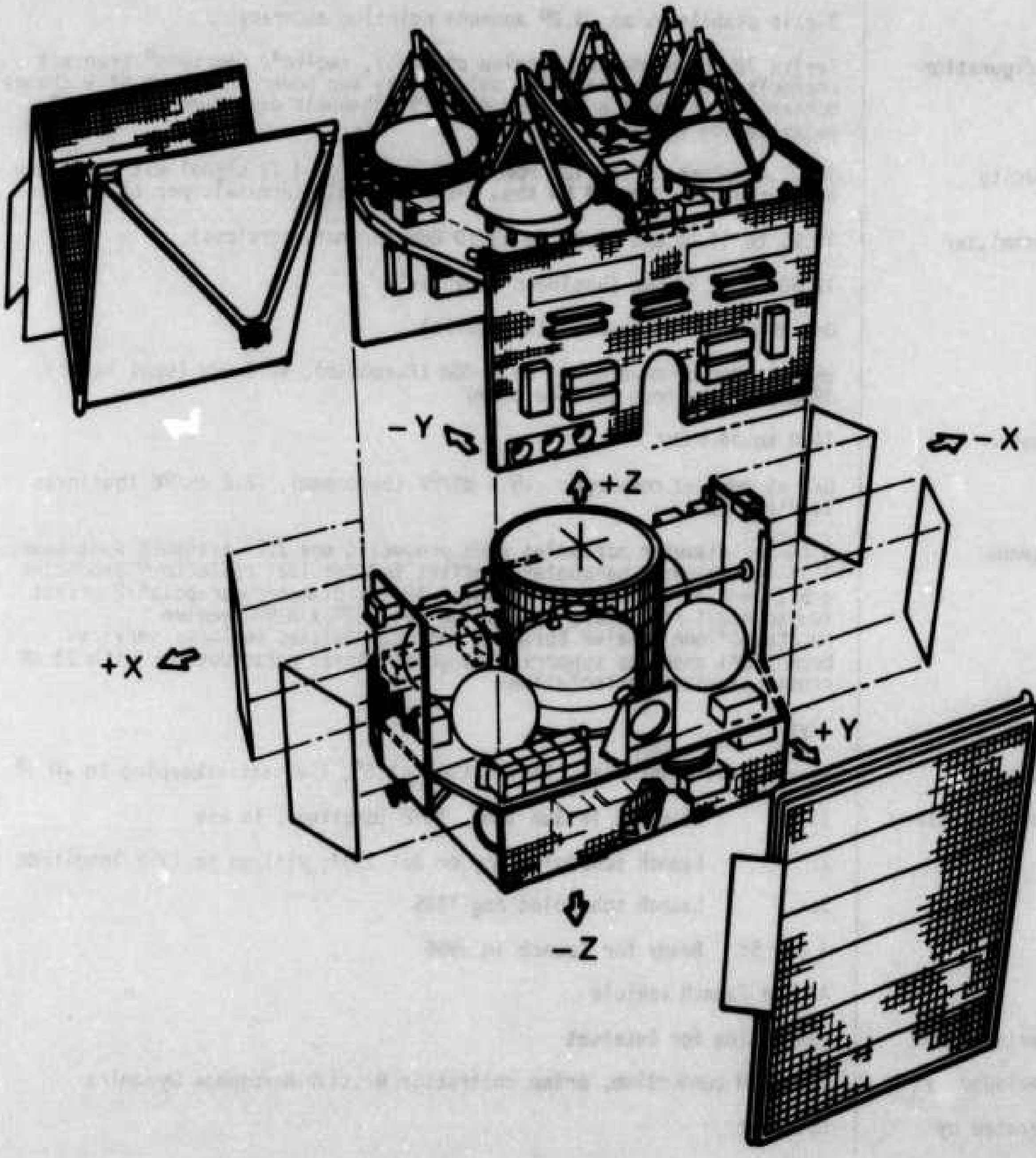


Figure 7-47. ECS Satellite

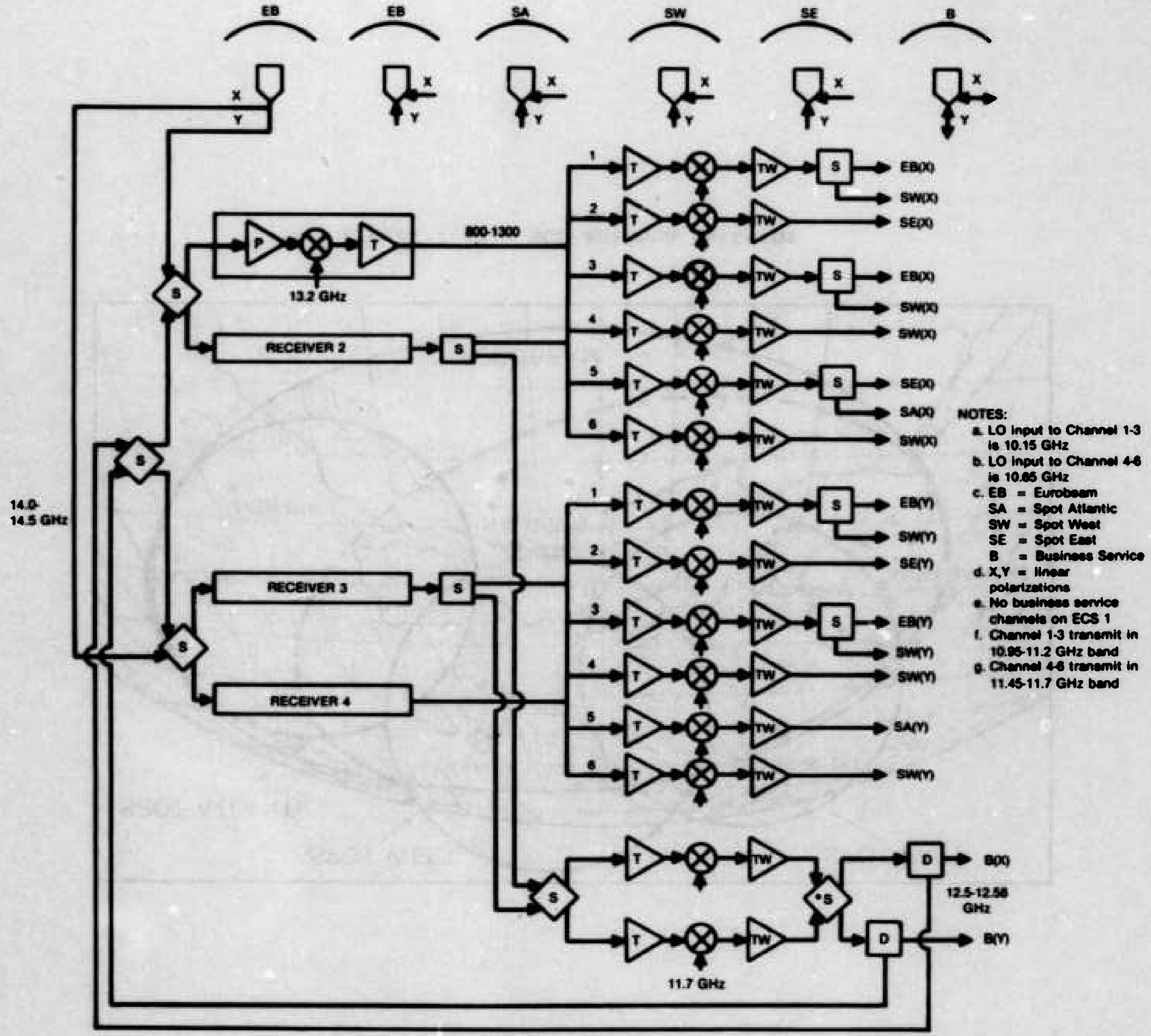


Figure 7-48. ECS Communication Subsystem

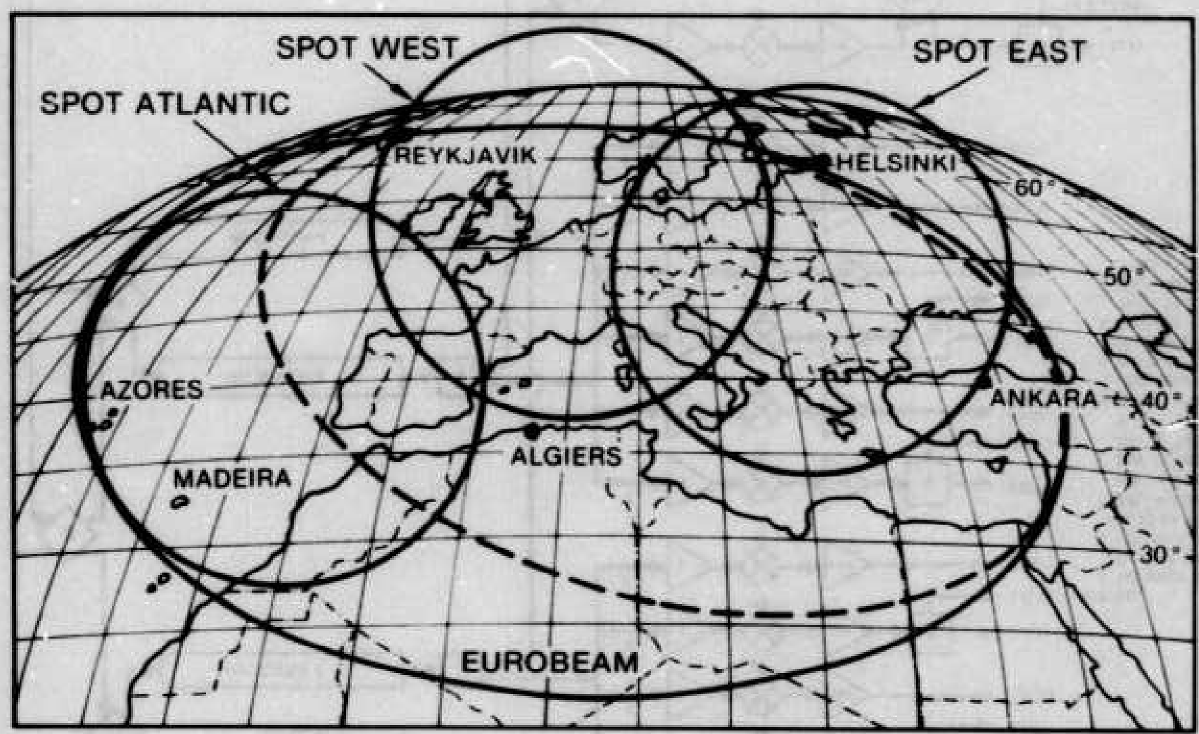


Figure 7-49. ECS Antenna Patterns

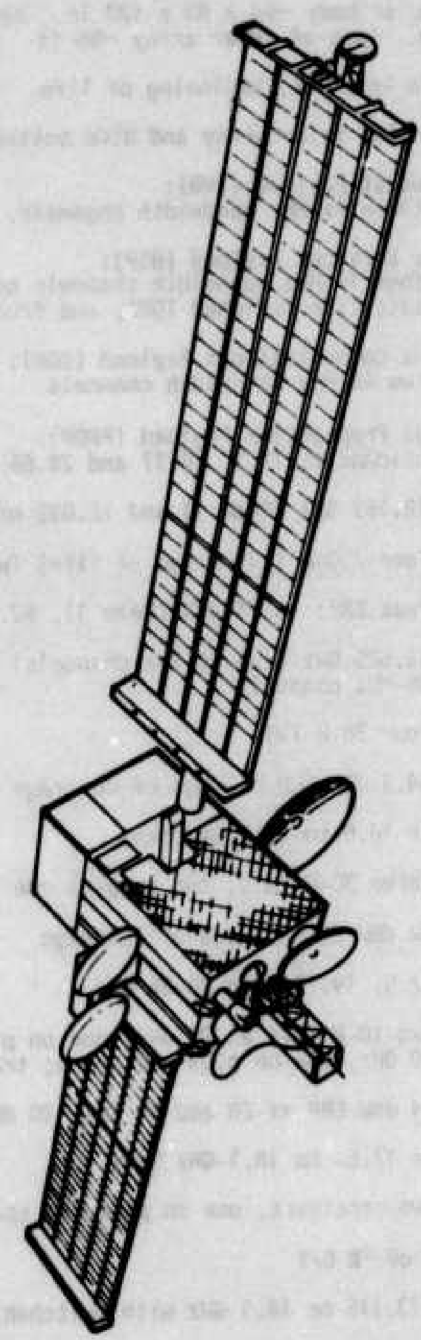


Figure 7-50. L-Sat Satellite

Table 7-28. L-Sat Details

Satellite	Rectangular body ~64 x 83 x 120 in., height of body plus antennas ~200 in., span of solar array ~95 ft ~3000 lb in orbit, beginning of life Sun-tracking solar array and NiCd batteries, ~3500 W beginning of life
Configuration	TV Broadcast Payload (TVB): three 27-MHz bandwidth channels, two of which are used at a time Business Services Payload (BSP): four 18-MHz bandwidth channels or two 18-MHz and one 36-MHz channel, satellite switched TDMA, and frequency reuse 20/30 GHz Communications Payload (COM): two 40-MHz bandwidth channels 20/30 GHz Propagation Payload (PROP): beacons at 12.5, 19.77 and 29.66 GHz
Transmitter	TVB: 12.169 GHz (Beam 1) and 12.092 or 12.245 GHz (Beam 2) Four 230-W (215 W end of life) TWTs, one on plus one spare per beam Peak ERP: 62.4 dBW (Beam 1), 62.7 dBW (Beam 2) BSP: 12.525 GHz (two 18-MHz channels) and 12.550 GHz (two 18-MHz or one 36-MHz channel) Four 30-W TWTs 44.3 dBW ERP at edge of coverage COM: In 18.8-to 19.5-GHz band Three 30-W TWTs, two on plus one spare 52 dBW ERP at edge of coverage PROP: 12.5, 19.77, and 29.66 GHz Two 10-W TWTs at 20 GHz, one on plus one spare; two 5-W TWTs at 30 GHz, one on plus one spare; transistor amplifier at 12.5 GHz 24 dBW ERP at 20 and 30 GHz, 10 dBW ERP at 12.5 GHz
Receiver	TVB: In 17.6- to 18.1-GHz band Two receivers, one on plus one spare 0 dB/^{o}K G/T BSP: ~13.175 or 14.1 GHz with switchable local oscillator Four receivers +1 dB/^{o}K G/T at edge of coverage COM: In 28- to 28.7-GHz band Two receivers, one on plus one spare +8 dB/^{o}K G/T at edge of coverage

Table 7-28. L-Sat Details (Continued)

Antenna	TVB:	40 x 80-in. reflector, $1^{\circ} \times 2.4^{\circ}$ beam, steerable within Europe (Beam 1); 47-in. reflector, 1.5° beam, steerable within Europe (Beam 2); 19-in. reflector, $2.4^{\circ} \times 3.7^{\circ}$ beam for European coverage (receive); all use circular polarization
	BSP:	47-in. reflector with five feed horns to form five adjacent beams, 1.2° (transmit), 1.1° (receive), linear polarization
	COM:	two 32-in. reflectors each forming one beam, 1.2° (transmit), 1° (receive), each steerable within Europe, linear polarization
	PROP:	three horns, 17.5° (earth coverage) at 12.5 GHz, 9° (centered on Europe) at 20- and 30-GHz, linear polarization
Design Life	10 yr	
Orbit	Synchronous equatorial, $\sim 18^{\circ}$W longitude	
Orbital History	Launch scheduled in 1986, Ariane launch vehicle	
Developed for	ESA	
Developed by	British Aerospace Dynamics with subcontractors from 11 European countries and Canada; Selenia (Italy) has prime responsibility for the payloads	

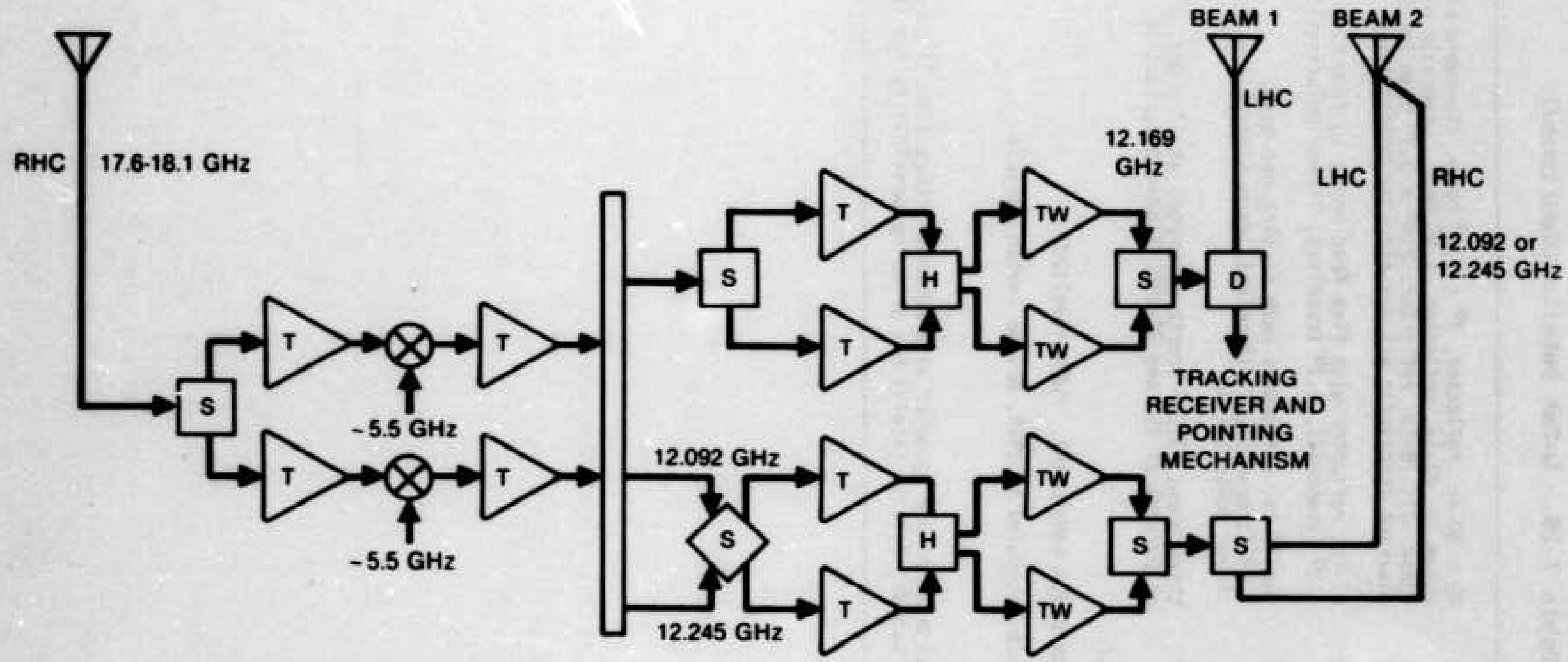
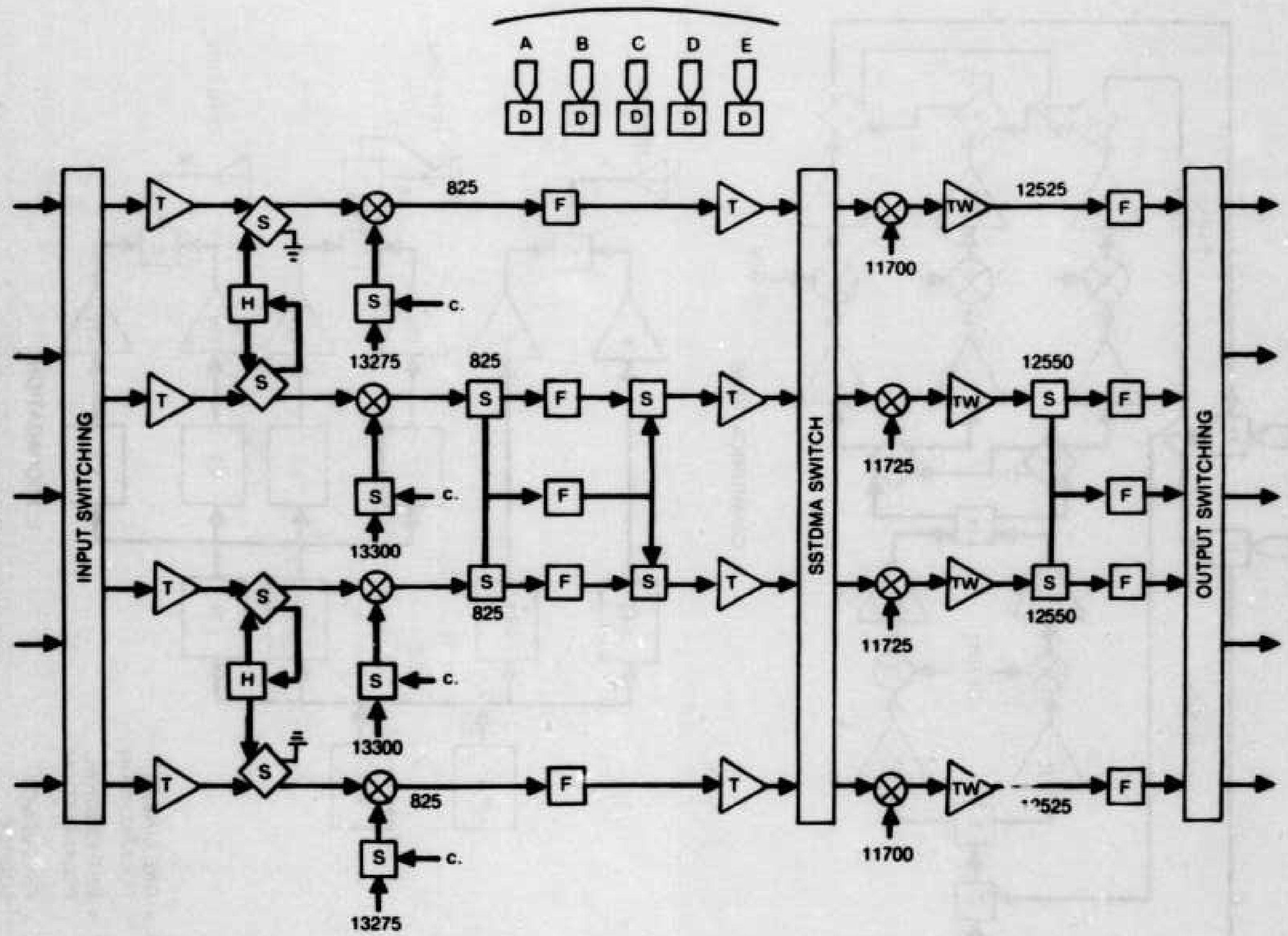


Figure 7-51. L-Sat Television Broadcast Payload



NOTES:

a. Beams A, B, and D use vertical polarization on the downlink, horizontal on uplink; beams C and E are opposite.
b. All filter bandwidths are 18 MHz except the two on the center row (36 MHz).
c. Alternate input to first mixer is about 900 MHz lower.

Figure 7-52. L-Sat Business Services Payload

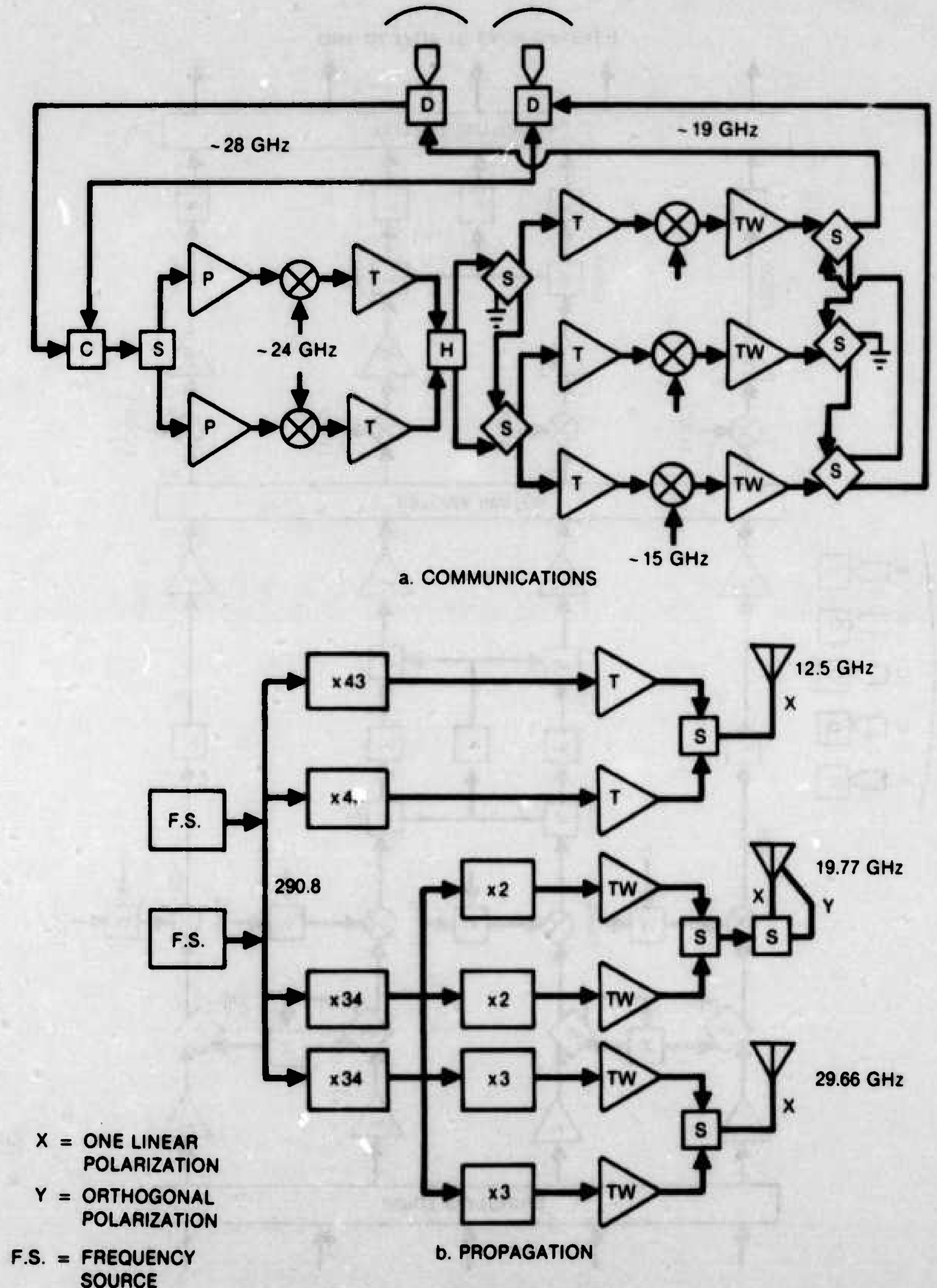


Figure 7-53. L-Sat 20/30-GHz Payloads

7.8 TELECOM 1 (Refs. 628-635)

Telecom 1 is a satellite being developed by and for France. The 4- and 6- GHz payload will be used for communications between France and its overseas territories. These include French Guiana and islands in the Caribbean, off the Newfoundland coast, and in the Indian Ocean. This payload will replace the Symphonie satellites in providing this service. The 7- and 8-GHz payload will provide global communications for the French military. It will serve fixed, transportable, and ship terminals. The 12- and 14-GHz payload will primarily support business communications within France and neighboring countries.

The satellite is a derivative of ECS and is similar in external appearance except for the antennas. Like ECS, the satellite has a service module and a payload module. The former includes the internal structure, three sides of the rectangular body, and the support subsystems including the solar arrays. These arrays have three sections each and are deployed in orbit. The payload module includes all the communications equipment mounted on the north, south, and earth-viewing faces of the body. The antennas, three parabolic reflectors and three horns, are all fixed to the earth-viewing face. Satellite and payload details are provided in Table 7-29.

The 4- and 6-GHz payload (Figure 7-54) has four channels. All are received through an earth coverage antenna and one of two redundant receivers. Each channel has a separate transmitter path. One channel is connected to a feed horn which forms a spot beam using one of the 12-GHz reflectors. The beam covers Guiana and the French Caribbean Islands. The other three channels are connected to a semiglobal coverage beam which includes France and all the territories listed above. This payload will be used for television and FDM/FDMA telephony.

Details of the 7- and 8-GHz military payload have not been publicized. Basically it consists of two earth coverage horns, one for reception and one for transmission, redundant receivers, and three TWTs.

Each of two channels is amplified by a TWT with the third being a spare.

The 12- and 14-GHz payload (Figure 7-54) has six channels. The equipment configuration is the same as the other payloads - redundant wideband receivers followed by channelized transmitters with three for two TWT redundancy. This payload has two antennas, both of which form elliptical beams whose -3 dB contours are about the size of France. Communications with other countries is planned within the -6 dB contour, which extends from northern Italy to England. One channel from this payload will be used for distribution of television programs. The other five channels will be used for business communications between small ground terminals (antenna diameter about 10 ft for terminals within the -3 dB satellite antenna contour). Individual links will have information rates varying between 2.4 kbps and 2.048 Mbps. System operation will employ demand assignment and TDMA with a transmission rate of 24.576 Mbps.

Because Telecom 1 operates in three frequency bands, considerable attention was given to frequency planning and techniques to minimize active and passive onboard interference. The 4-GHz transmission frequencies were chosen to avoid second harmonics in the 8-GHz receiver. Also, the 7-GHz transmission frequencies were chosen so that all harmonics were above the 14-GHz receiver passband.

Three Telecom 1 satellites are being built. The system will begin operations after launch of the first satellite in spring 1984. The second satellite will be launched in the fall of 1984 as a spare, and the third will be kept on the ground until needed in orbit. A Telecom 2 system, for use in the 1990s, is being studied.

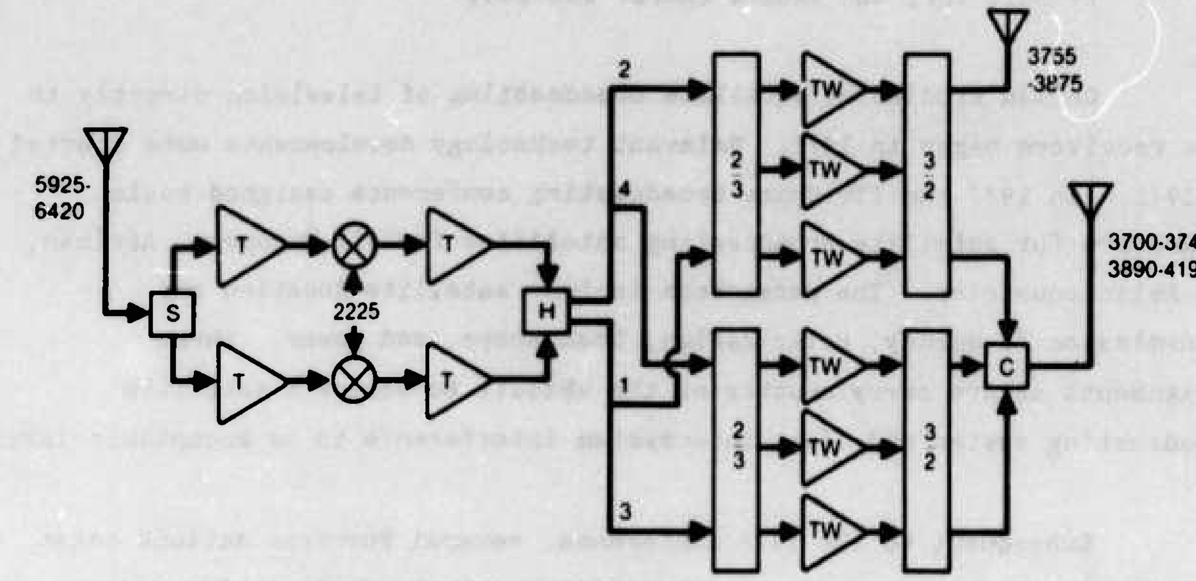
Table 7-29. Telecom 1 Details

Satellite	Rectangular body ~4-1/2 ft x 4-1/2 ft x 5 ft; deployed solar arrays span ~60 ft	
	1430 lb in orbit, beginning of life	
	Solar cells and NiCd batteries, ~1000 W end of life	
	3-axis stabilization, ~0.2° antenna pointing accuracy	
Configuration	4/6-GHz:	two 40-MHz bandwidth and two 120-MHz bandwidth single conversion repeaters
	7/8-GHz:	two 40-MHz bandwidth single conversion repeaters
	12/14-GHz:	six 36-MHz bandwidth repeaters
Capacity	4/6-GHz:	~1000 voice circuits or 1 TV transmission per 40-MHz repeater
	12/14-GHz:	25 Mbps per repeater with small (~10 ft antenna) ground terminals
Transmitter	4/6-GHz:	3700 to 3740, 3755 to 3875, 3890 to 3930, and 4075 to 4195 MHz
		One 8.5-W TWT per repeater plus two spares
		ERP: 28 dBW over France, 26.5 dBW over coverage area (ch. 1, 3, 4); 35 dBW over coverage (ch.2)
	7/8-GHz:	in 7250 to 7370 MHz band
		One 20-W TWT per repeater, plus one spare
		ERP: 27 dBW at edge of coverage
	12/14-GHz:	12504 to 12750 MHz
		One 20-W TWT per repeater plus one spare for every two repeaters
		ERP: 47 dBW over France[a]
Receiver	4/6-GHz:	5925 to 5965, 5980 to 6100, 6115 to 6155, and 6300 to 6420 MHz
		One active plus one spare receiver
		G/T $\geq$-13.7 dB/°K
	7/8-GHz:	in 7950 to 8150 MHz band
	12/14-GHz:	14004 to 14250 MHz
		One active plus one spare receiver
		G/T +6.3 dB/°K over France[a]
Antenna	4/6-GHz:	earth coverage horn, 16.7 dB gain at edge of coverage (receive); one helix illuminates one of the 12 GHz reflectors to provide a spot beam over Guyana and French Carribean islands, ~28 dB gain (ch. 2 transmit); five helixes illuminate a reflector to provide semiglobal coverage (ch. 1, 3, 4 transmit)

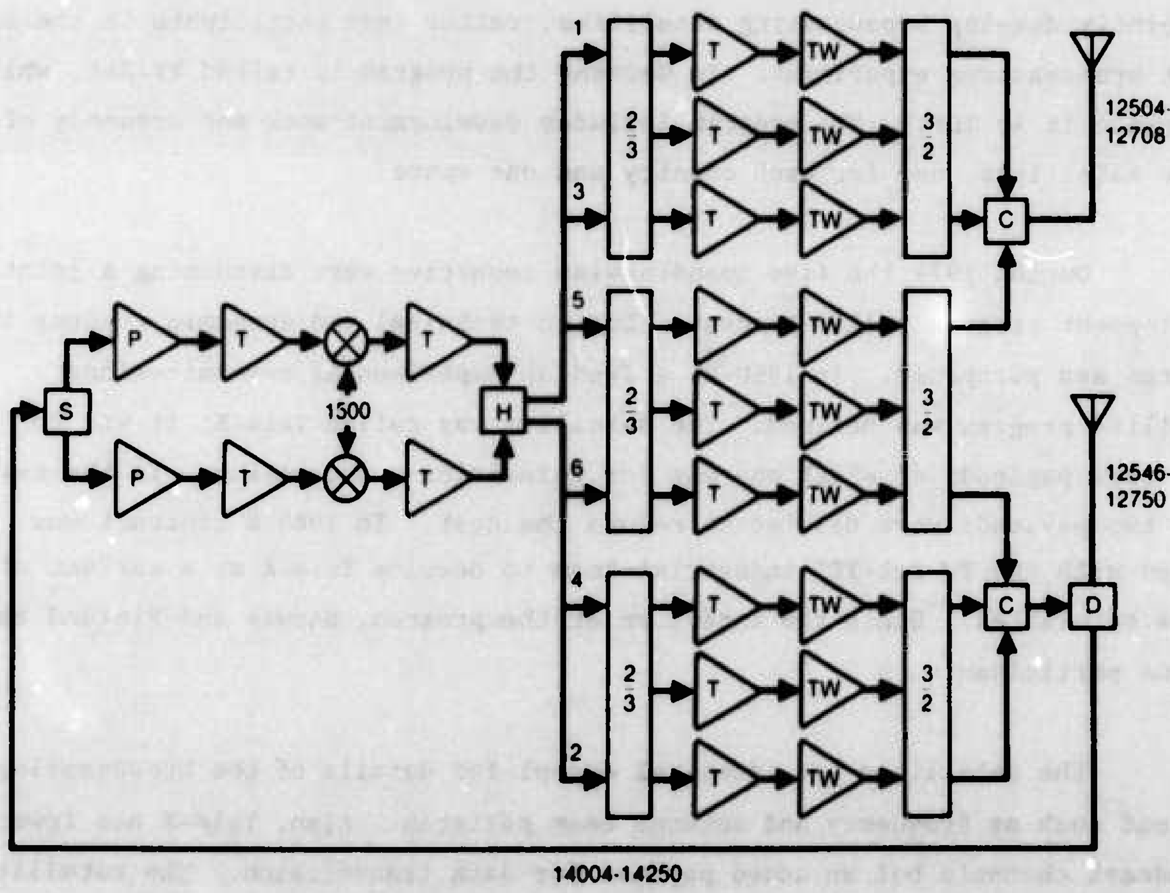
Table 7-29. Telecom 1 Details (Continued)

	7/8-GHz: two earth coverage horns, one transmit, one receive, ~17 dB gain at edge of earth
	12/14-GHz: two offset fed parabolic reflectors, each 31 x 48 in., 1.34° x 2.04° beam, one for odd channel transmit, the other for even channel transmit and all reception; linear polarization
Design Life	7 yr
Orbit	Synchronous equatorial, $\pm 0.05^{\circ}$ stationkeeping N-S and E-W
Orbital History	1: Launch scheduled May or Jul 1984, will go to 8°W longitude
	2: Launch scheduled Nov 1984 or Jan 1985 will go to 5°W longitude
	3: Probable launch 1986 or later
	Ariane launch vehicle
Developed for	Direction General des Telecommunications (French National Telecommunications Agency)
Developed by	MESH Consortium, Matra (France) is prime contractor
Operated by	Direction General des Telecommunications

[a]Ground terminals in neighboring countries may use the satellite by accepting up to 3 dB lower performance.



a. 4/6-GHz



b. 12/14-GHz

Figure 7-54. Telecom 1 Communication Subsystem

7.9 TV-SAT, TDF, and TELE-X (Refs. 635-643)

German studies of satellite broadcasting of television directly to home receivers began in 1971. Relevant technology developments were started in 1972. In 1977 the ITU Space Broadcasting conference assigned basic parameters for satellite broadcasting satellites for all European, African, and Asian countries. The parameters include satellite location and transmission frequency, polarization, beam shape, and power. These assignments assure every country of the ability to deploy a satellite broadcasting system and limit intersystem interference to an acceptable level.

Subsequent to the 1977 conference, several European nations began planning initial, or preoperational, systems. Both single nation and multination systems were considered. In late 1979 Germany and France agreed to jointly develop broadcasting satellites, rather than participate in the ESA L-Sat broadcasting experiment. In Germany the program is called TV-Sat, while in France it is TDF.* The program includes development work and assembly of three satellites, one for each country and one spare.

During 1979 the five Scandinavian countries were discussing a joint development program called Nordsat. Due to technical and economic reasons the program was postponed. In 1980-81 a Swedish experimental communications satellite program was defined. The satellite was called Tele-X; it was to have four payloads of which one was for television broadcasting. In the next year two payloads were deleted to reduce the cost. In 1983 a contract was signed with the TV-Sat/TDF industrial team to develop Tele-X as a variant of those satellites. Since the inception of the program, Norway and Finland have become participants.

The satellites are identical except for details of the broadcasting payload such as frequency and antenna beam patters. Also, Tele-X has fewer broadcast channels but an added payload for data transmission. The satellites

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*Telediffusion de France, the name of the national broadcasting company.

are composed of several modules, as shown in Figure 7-55. The propulsion module includes both a liquid bipropellant assembly and ion thrusters. The former is used both for the apogee maneuver and on-orbit; the latter is used for stationkeeping. The service module includes the attitude control, telemetry and command, and power regulation functions. The solar arrays are another module. They are composed of rigid rectangular frames supporting flexible blankets on which solar cells are mounted. The communications module includes all payload electronics and the thermal radiators for the payload. The antenna module includes the feed tower and the two large reflectors, which are folded against the tower for launch.

The 1977 conference allocated five channels each to Germany and France. The TV-Sat/TDF communication subsystem (Figure 7-56) includes all five channels, although only three may be operated simultaneously. Follow-on satellites will include additional electronics to provide redundancy for each channel and larger solar arrays to provide power for five channels. All five channels are accomodated by the wideband receivers. Each channel has a separate driver amplifier and TWT. The saturated output power of each TWT is 250 W. Values of other subsystem parameters are given in Table 7-30.

The Tele-X broadcasting payload uses the same hardware as TV-Sat and TDF except that only three channels are implemented. The second Tele-X payload has uplinks in the 14-GHz band and downlinks in the 12.5-GHz band. Two channels are provided, one each of 40- and 100-MHz bandwidth. They will be used for data transmissions and distribution of TV programs between terminals larger than those used with the broadcast payload.

Both TV-Sat and TDF are scheduled for launch in the second half of 1984. Both nations will use two channels for TV braodcasting. Germany will use the third for broadcasting more than one dozen high quality stereo audio programs. France may use the third channel in a variety of ways. Tele-X is scheduled for launch in 1986. All three satellites will be positioned at locations assigned by the 1977 conference.

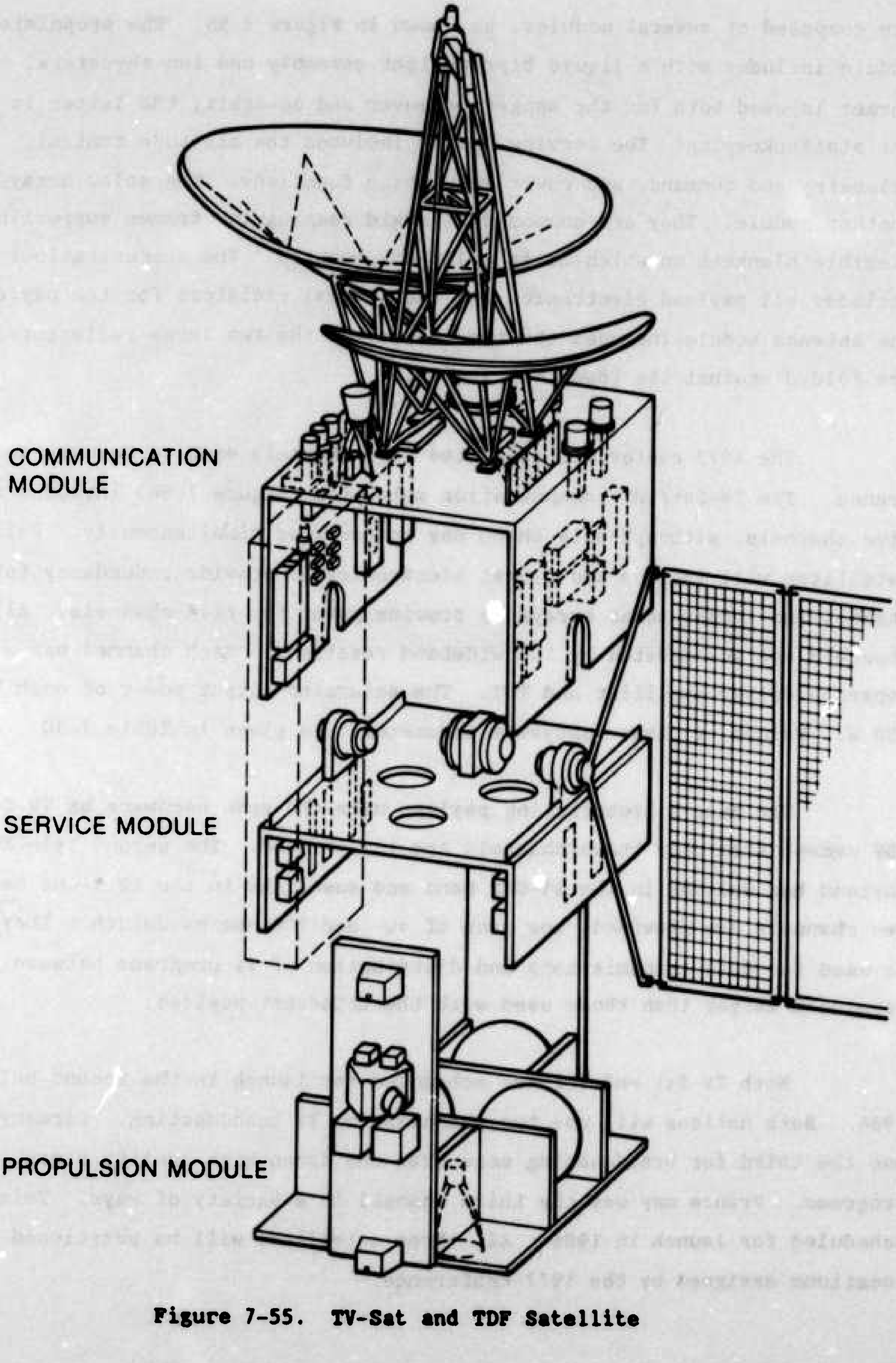


Figure 7-55. TV-Sat and TDF Satellite

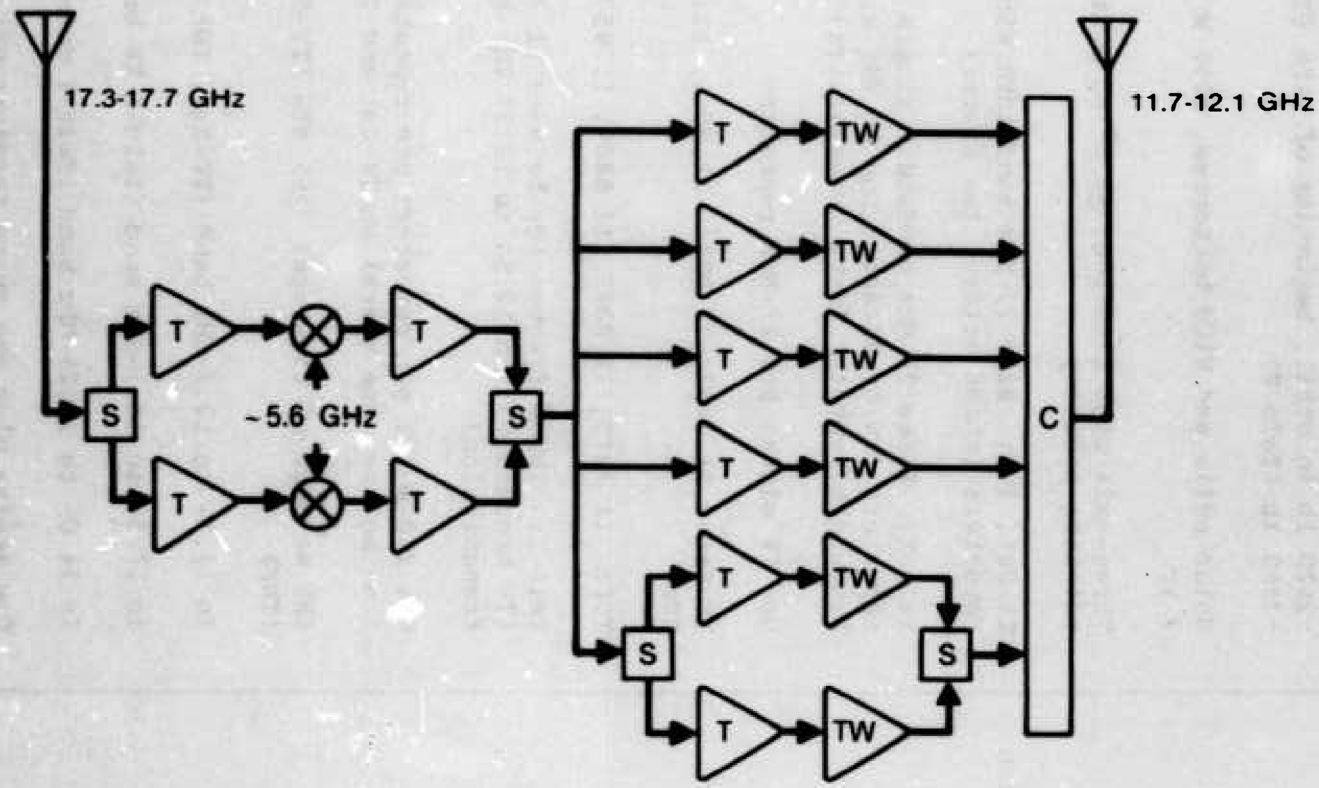


Figure 7-56. TV-Sat and TDF Communication Subsystem

Table 7-30. TV-Sat, TDF, and Tele-X Details

Satellite	Rectangular body, ~63 x 90 x 95 in, span of solar arrays 63 ft ~2620 lb in orbit, beginning of life (TV-Sat, TDF), ~2860 lb (Tele-X) Solar cells and NiCd batteries, 2850 W minimum after 7 yr Three-axis stabilization, $\pm 0.1^{\circ}$ or better antenna pointing accuracy
Configuration	TV-Sat, TDF: Five 27-MHz bandwidth single conversion repeaters (three active, two spares) Tele-X: Three 27-MHz bandwidth single conversion repeaters (TV broadcast); one 40-MHz and one 100-MHz bandwidth repeater (data transmission)
Capacity	One TV signal per 27-MHz repeater
Transmitter	TV-Sat: 11.7467, 11.8234, 11.9001, 11.9768 and 12.0535 GHz TDF: 11.7275, 11.8042, 11.8809, 11.9576 and 12.0344 GHz Tele-X: Three frequencies between 11.75 and 12.48 GHz (TV broadcast); in 12.50 to 12.75 GHz band (data transmission) One 250-W TWT per repeater; one repeater with two TWTs (one active, one spare) on TV-Sat and TDF ERP at edge of coverage: $\geq$65 dBW (TV-Sat), 63.5 dBW (TDF)
Receiver	In 17.3- to 17.7-GHz band (TV-Sat, TDF) In 17.3- to 18.1-GHz band (Tele-X TV broadcast) In 14.0- to 14.25-GHz band (Tele-X data transmission) One active plus one spare receiver per frequency band

Table 7-30. TV-Sat, TDF, and Tele-X Details (Continued)

Antenna	TV-Sat: two offset fed 67 x 98 in. parabolic reflectors, one forms $0.72^{\circ} \times 1.62^{\circ}$ LHCP transmit beam, one forms $0.5^{\circ} \times 1.13^{\circ}$ RHCP receive beam TDF: two offset fed parabolic reflectors, one forms $0.98^{\circ} \times 2.5^{\circ}$ RHCP transmit beam, one forms $\sim 0.7^{\circ}$ LHCP receive beam Tele-X: two offset fed parabolic reflectors for TV broadcast, one forms LHCP transmit beam, one forms RHCP receive beam Transmit antennas' cross polarized component at least 33 dB below operating polarization
Design Life	7 yr
Orbit	Synchronous equatorial, stationkeeping to $\pm 0.1^{\circ}$N-S and E-W
Orbital History	TV-Sat: Launch scheduled Sep 1985, will go to 19°W longitude TDF: Launch scheduled Nov 1985, will go to 19°W longitude Tele-X: Launch scheduled 1986, will go to 5°E longitude Ariane launch vehicle
Developed for	TV-Sat: Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt and Deutsche Bundespost TDF: Telediffusion de France and Centre National d'Etudes Spatiales Tele-X: Swedish Space Corporation acting for Swedish Board of Space Activities
Developed by	Eurosatellite Consortium, MBB prime contractor for TV-Sat, Aerospatiale prime contractor for TDF and Tele-X
Operated by	TV-Sat: Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt and Deutsche Bundespost TDF: Telediffusion de France

7.10 UNISAT (Refs. 644-647)

Unisat is a British satellite being developed for both TV broadcasting and business communications. Former names include UKSat and Halley. The project began in March 1982 when the British government authorized use of direct satellite broadcasting of television in Britain. The satellite is a derivative of the ECS satellite. It will have the same basic design, but will be heavier and will have longer solar arrays. Figure 7-57 is a picture of the satellite. The antenna on the earth-viewing face is for the television broadcasting payload. The two deployed antennas on opposite sides are for the business communications payload.

The TV braodcasting payload will have four of the five channels that were assigned to Britain at the 1977 ITU space broadcasting conference. Nominally, two will be used at a time; the provision of four provides redundancy. The BBC will use this payload. The Independent Broadcasting Authority of Britain could use the channels on a second satellite.

The business payload will have six channels, of which four may be used simultaneously with two broadcasting channels. Other combinations are possible, subject to the limit on available power. These channels are similar in design to the French Telecom 1 12/14-GHz payload. Their use will likewise be similar; i.e., for digital links connecting relatively small ground terminals at a large number of businesses. The payload design includes two beams, one for Britain and a part of West Europe and the other for North America. Beyond British domestic links, use of these beams is uncertain because of potential conflicts with the charters of Intelsat and Eutelsat. However, it has been mentioned that Intelsat is considering leasing satellite capacity on Unisat in order to provide trans-Atlantic business services.

Table 7-31 lists the current parameter values for Unisat. Three satellites are being built. The first two are scheduled to be launched in 1986.

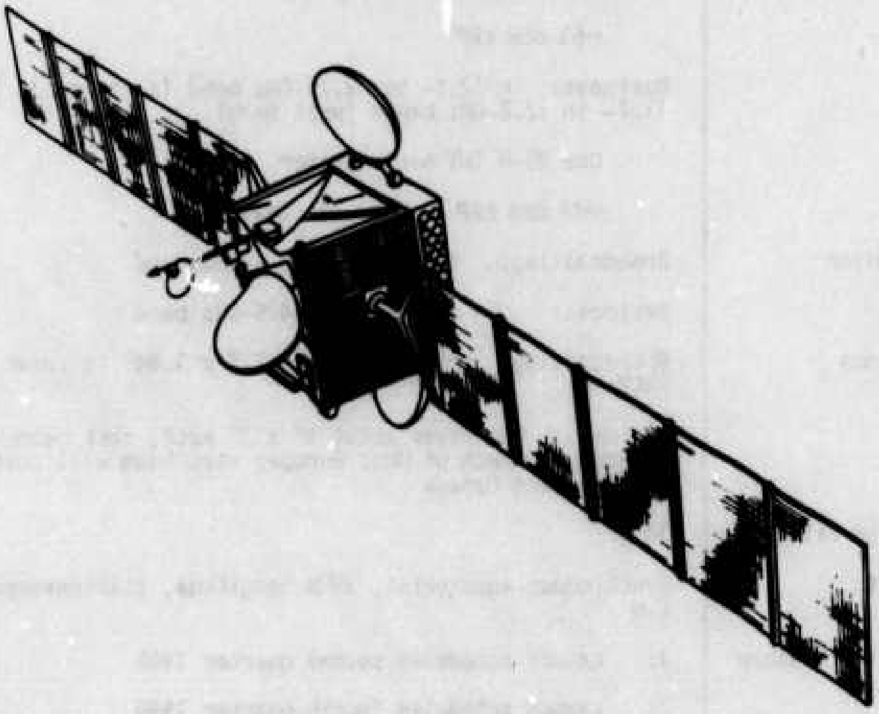


Figure 7-57. Unisat Satellite

Table 7-31. Unisat Details

Satellite	Rectangular body, 4-1/2 to 6 ft each dimension, span of solar arrays ~60 to 65 ft ~1870 lb in orbit, beginning of life Solar cells and NiCd batteries, ~2300 W beginning of life
Configuration	Broadcasting: four 27-MHz bandwidth repeaters (two active plus two spares) Business: six 36-MHz bandwidth repeaters (four active plus two spares)
Transmitter	Broadcasting: four of 11.785, 11.862, 11.938, 12.015 and 12.092 GHz One 200-W TWT per repeater ~63 dBW ERP Business: in 12.5- to 12.75-GHz band (east beam), in 10.95- to 11.2- or 11.7- to 12.2-GHz bands (west beam) One 20-W TWT per repeater ~44 dBW ERP at edge of coverage
Receiver	Broadcasting: in 17.3- to 18.1-GHz band Business: in 14.0- to 14.5-GHz band
Antenna	Broadcasting: transmit beam $0.72^{o} \times 1.84^{o}$ to cover the United Kingdom, RHCP Business: two beams about $1^{o} \times 3^{o}$ each; east beam will cover United Kingdom and much of West Europe; west beam will cover eastern U. S. and southeastern Canada
Design Life	10 yr
Orbit	Synchronous equatorial, 13^{o}W longitude, stationkeeping to $\pm 0.1^{o}$N-S and E-W
Orbital History	1: Launch scheduled second quarter 1986 2: Launch scheduled fourth quarter 1986 Ariane or Shuttle launch vehicle
Developed for	United Satellites Ltd (a joint venture of British Aerospace, Marconi, and British Telecom)
Developed by	British Aerospace
Operated by	United Satellites Ltd

7.11 ITALSAT (Refs. 648-653)

Italsat is a major element of the Italian national space plan. The plan defines objectives in space research and space technology. Many objectives are realized in multinational programs, but Italsat is being developed entirely in Italy. It is based on experience gained in the Sirio program. Italsat is a preoperational satellite intended to be as similar as possible to the operational satellites. Its goals are to:

a. Prove the national capability to design and develop a medium size satellite.
b. Demonstrate, in orbit, most or all of the technologies required for the operational system.
c. Demonstrate advanced telecommunication services to users.
d. Support new millimeter wave propagation experiments.

The technology demonstration will be strengthened by strong Italian participation in the L-Sat 20/30-GHz payloads.

The Italsat is a three-axis-stabilized satellite. Its design is new, rather than a derivative of an older satellite. The detailed design phase began in the fall of 1983. Figure 7-58 is a sketch showing the basic satellite features. The rectangular body and multipanel solar wings are typical features of three-axis-stabilized designs. All support subsystems and communications electronics are contained within the body. The propulsion subsystem is a bipropellant type and is used both for the apogee maneuver and in-orbit. The power subsystem uses nickel-hydrogen batteries. The two large antennas are folded against the satellite body for launch and deployed in orbit; each has a positioning mechanism for fine pointing control. The other antennas are fixed to the satellite; their pointing is set by the satellite attitude.

Italsat has three payloads. The largest is for point-to-point domestic communications. This payload will be used for high volume telephony

between major nodes of the Italian terrestrial network. The second payload is for "specialized services". This refers to business communications, including voice, data, and facsimile transmissions between small ground terminals at customer locations. The smallest payload is for propagation measurements Recent values for payload and satellite parameters are given in Table 7-32.

The 20/30-GHz domestic communications payload (Figure 7-59) includes uplink demodulation, baseband-switched TDMA, and remodulation. Each of the two large antennas generates three spatially separated beams (Figure 7-60), which are used for both transmission and reception. Every beam uses a separate frequency, although spatial reuse of frequencies is being considered for the operational system. The same frequency pattern is used in each antenna, so that only two local oscillator frequencies convert the uplinks to a common set of intermediate frequencies. The signals are then routed to 120 Mbps QPSK demodulators, baseband switches operating at the TDMA burst rate, and 120 Mbps QPSK modulators operating at the dowlink frequencies. An optional 360 Mbps channel is being considered because the operational system is expected to use both 120 and 360 Mbps to accomodate ground terminals with different traffic demands. The modulator outputs are routed to the redundant TWTs. In addition to the communications receivers, the payload has tracking receivers for each antenna. These derive pointing information which is used to control the antenna positions.

The specialized services payload also operates in the 20- and 30-GHz bands. It has one antenna generating a single beam which includes all of Italy (Figure 7-60). The tentative payload configuration (Figure 7-61) has four channels. The final configuration and specific uplink and downlink frequencies will be determined after the conclusion of some detailed studies concerning the larger domestic communications payload. The channels of this payload will be used by ground terminals with 10- to 18- ft diameter antennas. Transmissions will be at a TDMA burst rate of 25 Mbps. Frequency hopping among the channels might be used.

The propagation experiments payload (Figure 7-61) generates three signals, near 20, 40 and 50 GHz, from a common oscillator. The 20-GHz signal is modulated by spacecraft telemetry data, and is radiated through the antenna of the specialized services payload. It serves as a tracking beacon for all Italian ground terminals using the satellite. The received power level can be used as a measure of propagation loss for uplink power control. The 40-GHz beacon is phase modulated by a 492-MHz sine wave and transmitted to most of Europe (Figure 7-60). The 50-GHz beacon has the same European coverage. It is unmodulated, but can be switched between orthogonal linear polarizations at 300 Hz.

Italsat is scheduled to be launched in the latter part of 1987. The following operational satellites are expected to enter service early in the 1990s.

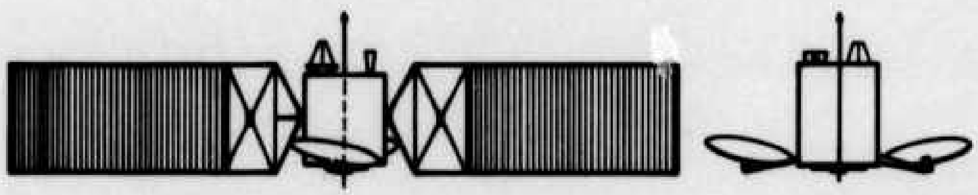


Figure 7-58. Italsat Satellite

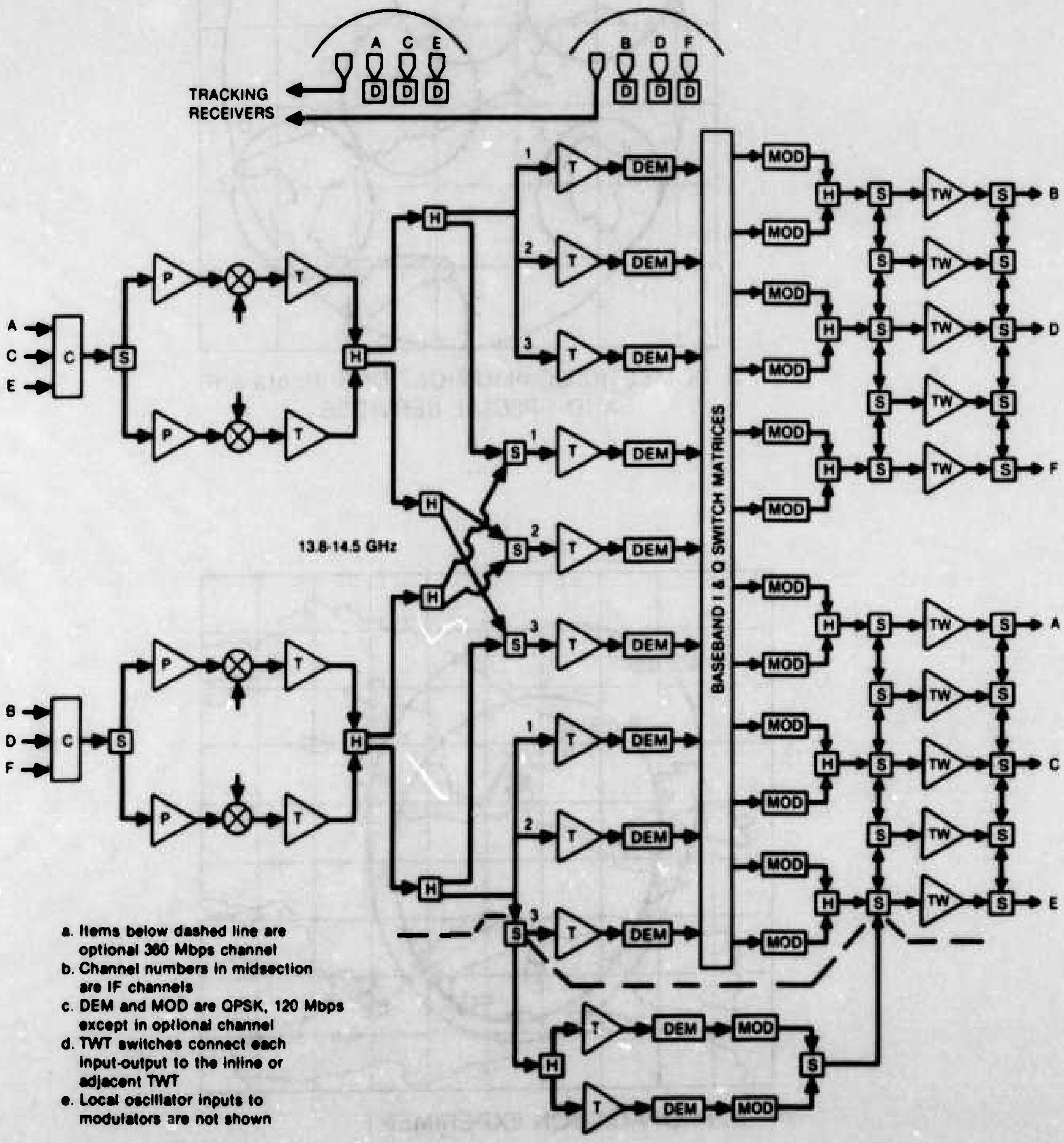
Table 7-32. Italsat Details[a]

Satellite	Rectangular body 60 x 60 x 66 in., satellite height (body plus antennas) 10 ft, span across deployed antennas 18 ft, span of solar arrays 45 ft	
	1500 lb in orbit, beginning of life	
	Solar cells and NiH_2 batteries. 1370 W minimum after 5 yr (sunlight), 760 W (eclipse)	
	Three-axis-stabilized, $\pm 0.2^\circ$ or better accuracy; multibeam antennas pointed to $\pm 0.05^\circ$ (goal 0.03°) via tracking of ground beacon	
Configuration	DC:[b]	Six 120-Mbps regenerative repeaters, perhaps with one switchable to 360 Mbps operation
	SS:[c]	Four 25-MHz bandwidth double conversion repeaters
	PE:[d]	Beacons at 19.7, 39.4 and 49.25 GHz
Transmitter	DC:	19.35, 19.45, 19.55, 19.65, 19.75 and one of 19.99, 20.07 and 20.15 GHz
		One 20-W TWT per frequency plus two spares for each three
		ERP 55.2 dBW at edge of coverage
	SS:	in 19.8- to 20.2-GHz band
		One 30-W TWT per repeater
		ERP 48 dBW at edge of coverage
	PE:	19.7-GHz, redundant 0.1 to 0.2-W transistor amplifiers
		39.4-GHz, 1-W Impatt amplifier, 52.9 dBW ERP
		49.25-GHz, 1-W Impatt amplifier, 54 dBW ERP
Receiver	DC:	in 28.8- to 30.0-GHz band plus tracking beacon at 27.5 GHz

Table 7-32. Italsat Details[a] (Continued)

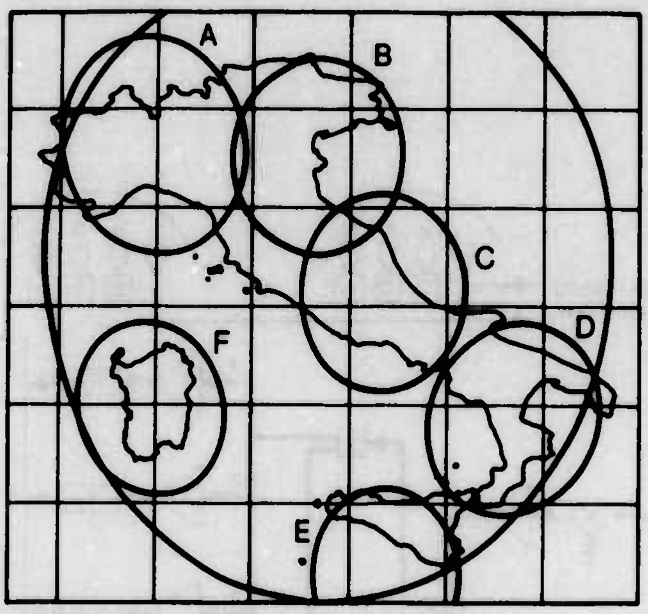
		Redundant receivers (one active, one spare) for each antenna
		G/T +16 dB at edge of coverage
	SS:	in 29.6- to 30.0-GHz band
		Redundant receivers (one active, one spare)
		G/T +5.7 dB at edge of coverage
Antenna	DC:	Two 77-in. diameter offset fed parabolic reflectors, each has three feed horns each generating one 0.45° transmit beam and one 0.31° receive beam, plus a 7-horn cluster for tracking a ground beacon; edge of coverage is the -3 dB transmit contour and -6 dB receive contour, linear polarization
	SS:	One 34-in. diameter Cassegrain generating one transmit and receive beam 1.35° (-3 dB), 1.55° (edge of coverage), linear polarization
	PE:	Two offset fed parabolic reflectors, one at 40 GHz, one at 50 GHz, 3.3° beam, circular polarization at 40 GHz, linear at 50 GHz (can be switched between horizontal and vertical at 300 Hz)
Design Life	5 yr	
Orbit	Synchronous equatorial, 13°E longitude, stationkeeping to ±0.1°N-S and E-W	
Orbital History	Launch scheduled in second half of 1987	
	Ariane (or Shuttle) launch vehicle	
Developed for	Italian National Research Council	
Developed by	Telespazio and Selenia	

[a]Numerical values are tentative.
[b]Point-to-point domestic communications payload.
[c]Specialized services payload.
[d]Propagation experiment.

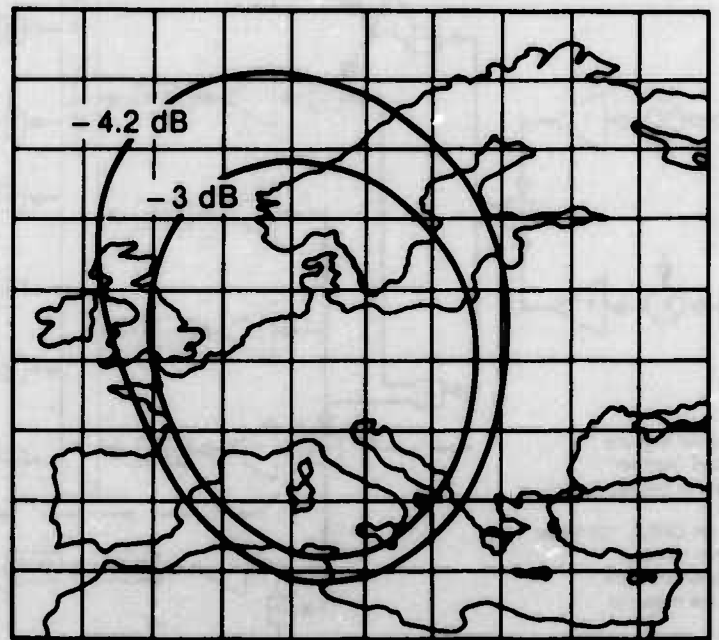


a. Items below dashed line are optional 360 Mbps channel
b. Channel numbers in midsection are IF channels
c. DEM and MOD are QPSK, 120 Mbps except in optional channel
d. TWT switches connect each input-output to the inline or adjacent TWT
e. Local oscillator inputs to modulators are not shown

Figure 7-59. Italsat Domestic Communications Payload



a. DOMESTIC COMMUNICATIONS (Spots A-F)
AND SPECIAL SERVICES



b. PROPAGATION EXPERIMENT

Figure 7-60. Italsat Coverages

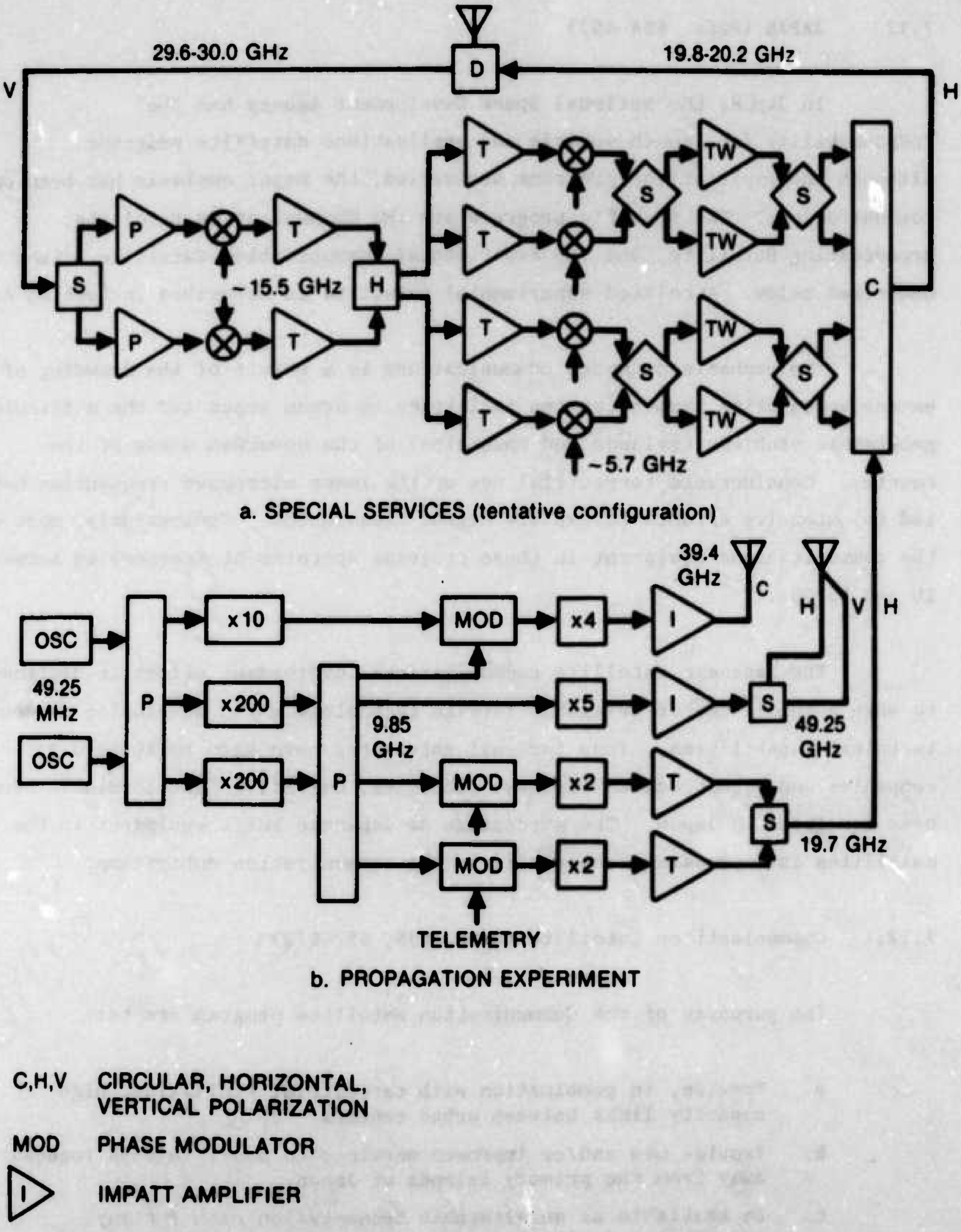


Figure 7-61. Italsat Special Services and Propagation Payloads

7.12 JAPAN (Refs. 654-657)

In Japan, the National Space Development Agency has the responsibility for launch vehicle and applications satellite programs. Although the applications programs are varied, the major emphasis has been on communications. The specific programs are the Communication Satellite, Broadcasting Satellite, and the Experimental Communication Satellite. Each is described below. A related experimental satellite is described in Section 8.8.

The emphasis on space communications is a result of the crowding of extensive existing communications facilities in urban areas and the difficult geographic problems (islands and mountains) of the nonurban areas of the country. Considerable terrestrial use of the lower microwave frequencies has led to extensive efforts to explore higher frequencies. Consequently, most of the communications equipment in these programs operates at frequencies between 10 and 35 GHz.

The Japanese satellite communications development effort is designed to make economic use of available foreign technology while developing internal technical capabilities. Thus far, all satellites have been built by U.S. companies under contract to Japanese companies, but all ground terminals have been developed in Japan. The percentage of Japanese-built equipment in the satellites is increasing, especially in the communication subsystems.

7.12.1 Communications Satellite (Refs. 655, 657-672)

The purposes of the Communication Satellite program are to:

a. Provide, in combination with terrestrial facilities, high capacity links between urban centers.

b. Provide new and/or improved services to small islands located away from the primary islands of Japan.

c. Be available as an alternate transmission path for any terrestrial facilities damaged by natural disasters.

The program uses two frequency bands: 4/6 GHz and 20/30 GHz. The latter band supports the first purpose; the former supports the second purpose. Both bands are available for emergency use.

The first phase of the program is based on the Medium Capacity Satellite for Experimental Purpose, commonly known as the CS. The CS, launched in 1977, has been used for a variety of tests and preoperational system demonstrations. Activities have included transponder characterization, tests of several transmission and multiple access techniques, gaining satellite control experience, and propagation measurements. After launch, the CS was named Sakura (Cherry Blossom)*.

The CS is a spin-stabilized satellite with a despun antenna, very similar to the NATO III satellite. The solar array is identical and many support subsystems are derived from NATO III subsystems. The communication subsystem (Figure 7-62) and antenna are new designs. This satellite has eight channels, each with a 200-MHz bandwidth. Two channels are in the 4- and 6-GHz band used by many commercial satellites. The other six channels are in the 17.7- to 21.2-GHz and 27.5- to 31-GHz bands. These channels were chosen from a frequency plan that allows 10 channels in these bands. This is the first use of these frequencies for standard communication links, although other satellites have equipment for special transmissions for propagation measurements at these frequencies. The satellite antenna is a despun horn whose axis is coincident with the satellite spin axis. It is mechanically despun, and the antenna beam is reflected toward the earth by a reflector oriented 45 deg from the spin axis. The reflector is not exactly flat, but is contoured to shape the K-band (20- and 30-GHz) beam to match the geography of the main Japanese islands. The 4- and 6- GHz beams use the same antenna, but are circular and are of a size that can cover all islands to be served by CS. Figure 7-63 is an illustration of this satellite, and Table 7-33 lists various details.

*The Japanese typically name satellites, which successfully reach orbit, after flowers.

The CS2 satellites were developed to follow the CS satellite in support of operational communications links. The newer satellites are almost identical to the CS. Differences are noted in Table 7-33. The CS2 communication subsystem, like the CS, has two 4/6-GHz channels and six 20/30-GHz channels. The bandwidths have been reduced but are still more than adequate for the chosen data rates. The communication subsystem configuration (Figure 7-64) has been modified, primarily to improve reliability. Also, improvements in microwave electronics since the CS was built have resulted in some satellite performance increases.

CS2A was launched early in 1983, and is now named Sakura. The 4/6-GHz channels are being used with a 107-Mbps TDMA network to tranmsit telephone and television between Tokyo and remote islands, such as Okinawa. The 20/30-GHz channels are being used with a 64-Mbps TDMA network for telephone transmissions between approximately eight major cities. Transportable terminals for each frequency band, with about 10-ft diameter antennas can provide FDMA links. All of these links are for public telecommunications. Business communications, like those available on the many U.S. domestic satellites, are not planned until introduction of the CS3 satellites at the end of the 1980s. This is a disappointment to many businesses, which desire to have such a service now.

7.12.2 Broadcasting Satellite (Refs. 655, 657, 666, 673-693)

The purposes for which satellite television broadcasting are used in Japan are to:

a. Extend current broadcasting to outlying areas and households on the main islands that have poor reception or none.

b. Provide new broadcasting services.

c. Promote technological developments.

d. Provide an alternative to terrestrial equipment, which may be damaged by natural disasters.

The first satellite in the program was the Medium Scale Broadcasting Satellite for Experimental Purpose (BSE or BS). It was named Yuri (Lily) after launch. This satellite was used for many technical measurements; operational testing, especially with transportable terminals; and gaining experience in the control of a three-axis-stabilized satellite. The operational phase of the program will use the BS2 satellites.

The BSE and BS2 satellites are very similar in design. The BS2 is shown in Figure 7-65. The antenna feed structure and dimensions are slightly different for the BSE. Both are three-axis-stabilized with deployed solar arrays. All equipment is contained within or on the sides of the rectangular body. The single large antenna is fixed to the satellite. The BS2 has improvements necessary to increase its life to five years, compared to three years for BSE. Also, the BS2 satellites will use a Japanese launch vehicle rather than the U.S. vehicle used for the BSE.

The communication subsystem is shown in Figure 7-66. The subsystem is relatively simple and supports only two channels. The antenna pattern is shaped to provide coverage of both the main and outlying islands of Japan. There are two categories of differences between the BSE and BS2. One is adjustments in the frequencies, polarization, and some other parameters to conform to the decisions of the 1977 ITU space broadcasting conference. The other is changes due to improvements in electronics; these are noted on the Figure. Details concerning both satellites are given in Table 7-34. The BSE was launched in April 1978. Television broadcasting ceased in June 1980 with the failure of the last TWT. Activities involving the satellite that did not depend on the TWTs continued until January 1982 when the attitude control fuel was exhausted. The first BS2 was launched early in 1984; the second launch is scheduled in 1985. The second will be a spare. Plans for a BS3 generation of larger satellites have begun, with 1988 the goal for their introduction.

Transmissions to the BSE and BS2s originate from either a fixed main terminal near Tokyo, or transportable terminals. The former has a 42-ft

antenna; the latter have 8-ft antennas for use in the main islands and 15-ft antennas for the remote islands. Home receiving antennas are as small as 40 inches in the main islands, and up to 10 ft in the remote islands.

7.12.3 Experimental Communications Satellite (Refs. 655, 694-696)

Japan is developing launch vehicle technology in addition to spacecraft technology. Their basic launch vehicle is the N rocket, which is based on the 1970 design of the U.S. Thor-Delta*. The first synchronous orbit mission for this launcher was the Engineering Test Satellite II (ETS II) (Section 8.8). This satellite was the direct predecessor of the Experimental Communication Satellite (ECS)** that was also launched by the N rocket. The purposes of the ECS program were development of techniques for launch and on-orbit control of synchronous satellites, propagation measurements, and communications experiments.

Both ETS II and ECS were based upon the Skynet I design. This was because the Skynet was sized to the Delta launch vehicle from which the N rocket was developed and all three satellites were built by the same manufacturer. Figure 7-67 is a picture of the ECS. Like Skynet and ETS II, ECS was spin-stabilized with a mechanically despun antenna. The solar array was mounted around the outside of the spinning body, and other subsystems were attached inside the spinning body on both sides of an equipment platform. The despun section had two parabolic antennas whose beamwidth was sized to cover Japan while minimizing radiation on adjacent nations. The larger antenna was for C-band (4 and 6 GHz), and the smaller was for K-band (31 and 34 GHz). There was also a 128-element C-band array mounted around the top end of the satellite body, which provided nearly omnidirectional coverage. The C-band equipment could be switched between the two C-band antennas. Various technical details concerning the satellite are given in Table 7-35.

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*An improved version, the N-2, is based on the mid 1970s Delta.

**No similarity with the European Communication Satellite that is also called ECS.

The communication subsystem of the ECS (Figure 7-68) had five basic sections: C- and K-band receivers (left side of the figure), an intermediate frequency section (middle), and C- and K-band transmitters (right side). The IF section handled only one signal at a time. By ground commands either transmitter and either receiver could be connected to the IF section, giving a total of four possible configurations. The bandwidth of the IF section could be switched to 10, 40, or 120 MHz. The 10-MHz option was intended for range and range rate measurements, and the wider bandwidths for the communications experiments.

ECS was launched in the beginning of February 1979, but was destroyed during apogee motor firing, apparently due to a collision with the launch vehicle third stage. The spare ECS was launched a year later and was destroyed by a failure of the apogee motor.

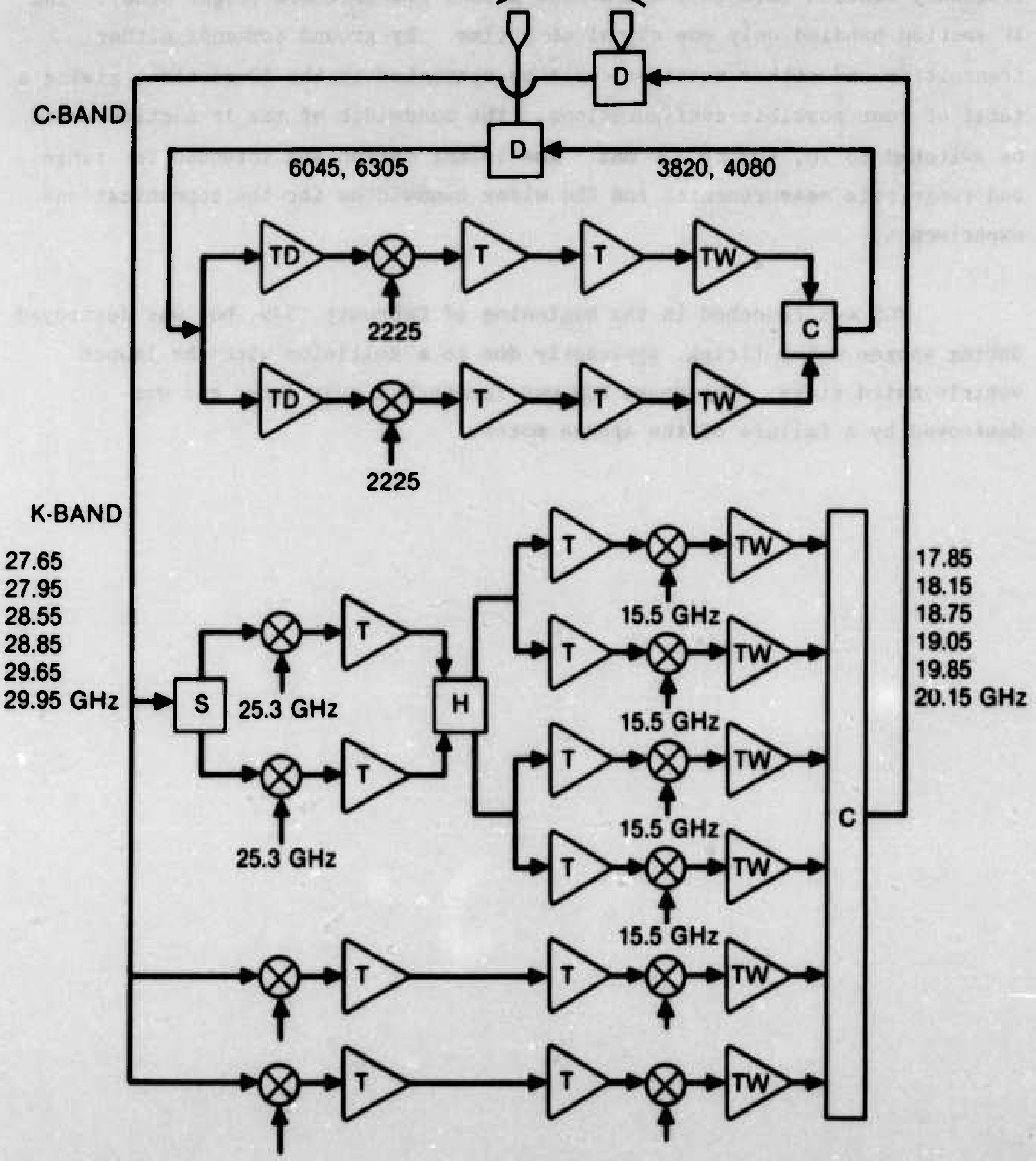


Figure 7-62. CS Communication Subsystem

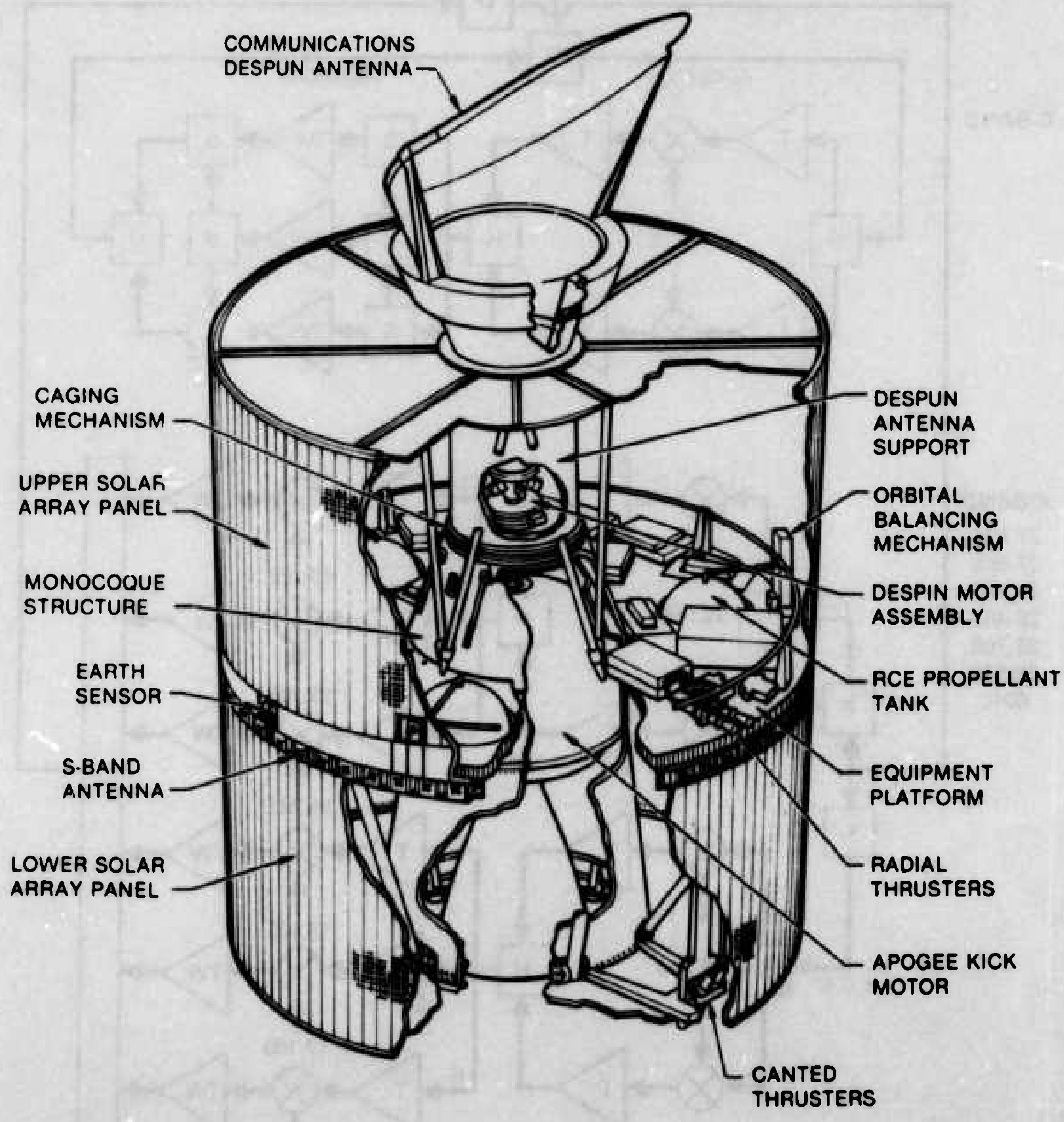


Figure 7-63. Japanese Communication Satellite (CS, CS2)

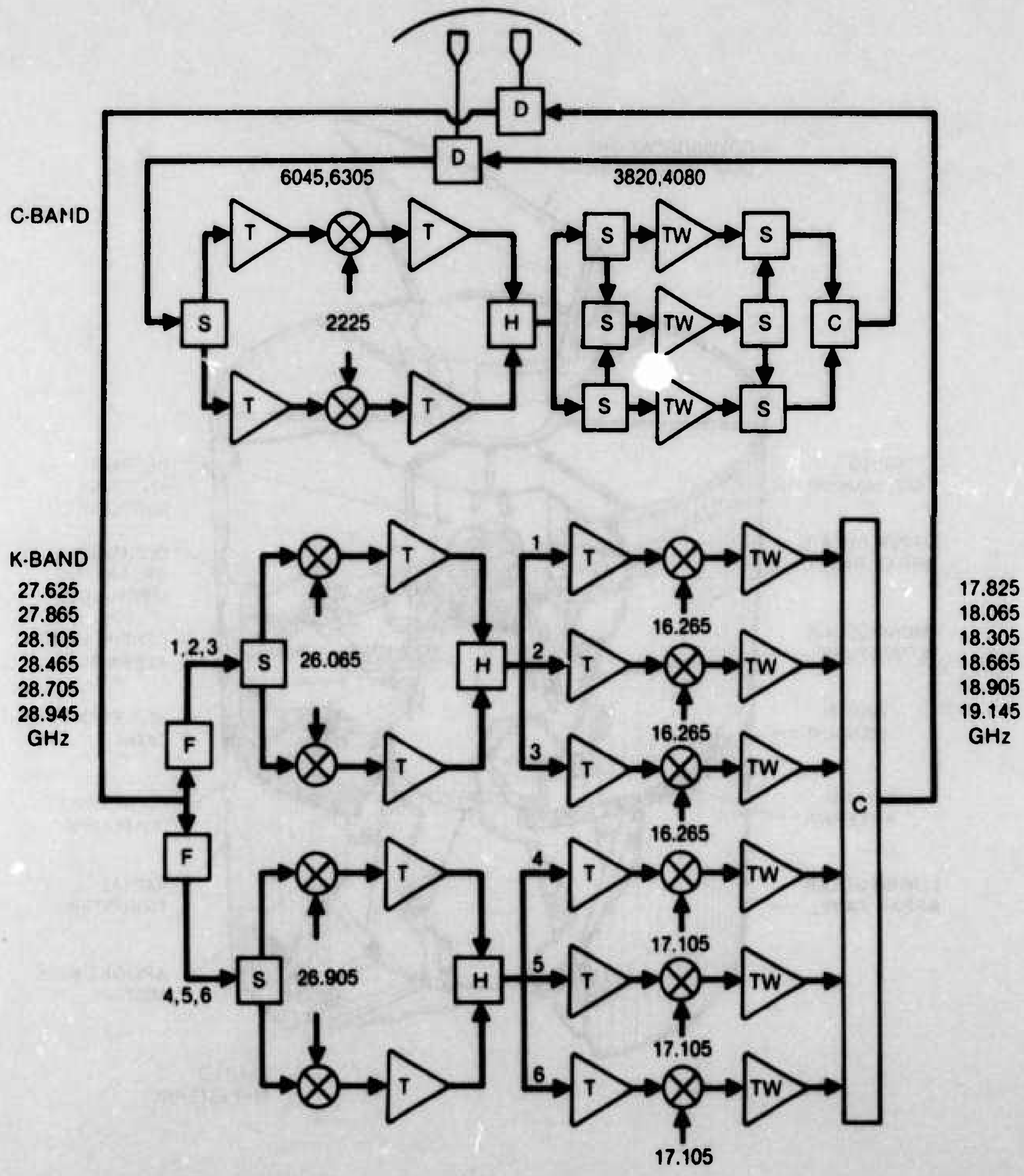


Figure 7-64. CS2 Communication Subsystem

Table 7-33. CS and CS2 Details

Satellite	Cylinder, 86-in. diameter, $88^a/81^b$ in. high, overall height $139^a/130^b$ in. $\sim750^a/770^b$ lb in orbit, beginning of life Solar cells and NiCd batteries, $529^a/540^b$ W at beginning of life, 422-W minimum after 3 yr^a, 409-W minimum after 5 yr^b Spin-stabilized, ~90 rpm, $\pm0.3^o$ antenna pointing accuracy (3σ)
Configuration	C-band: Two $200^a/180^b$-MHz bandwidth single conversion repeaters K-band: Six $200^a/130^b$-MHz bandwidth double conversion repeaters
Capacity[b]	C: 192 two-way voice circuits plus 2 TV programs per repeater K: 1920 two-way voice circuits per repeater
Transmitter	C: 3820 and 4080 MHz, 6-W TWT per repeater, 29.5 dBW per repeater minimum ERP K: 17.7- to 21.2-GHz band[c]: 5-W TWT per repeater, 37 dBW per channel minimum ERP
Receiver	C: 6045 and 6305 MHz, active plus spare receiver[b] noise figure $9^a/\leq6^b$ dB, G/T >-6.0 dB/$^oK^b$ K: 27.5- to 31.0-GHz band[c], 2 active plus 2 spare receivers, noise figure $13^a/<12^b$ dB, G/T >-3.8 dB/$^oK^b$
Antenna	Despun horn and 45^o contoured reflector, 37-in. diameter aperture, circular polarization Minimum gain is 33 dB at 18 and 30 GHz (Japanese main islands only), 25 dB at 4 and 6 GHz (main and outlying islands)
Design Life	3 yr^a/5 yr^b
Orbit	Synchronous equatorial, $\pm0.1^o$E-W and N-S stationkeeping
Orbital History	CS: Launched 15 Dec 1977, 135^oE longitude Delta 2914 launch vehicle CS2A: Launched 4 Feb 1983, 132^oE longitude CS2B: Launched 5 Aug 1983, 136^oE longitude Japanese N-2 launch vehicle
Developed for	National Space Development Agency (NASDA) of Japan
Developed by	Ford Aerospace and Communications Corporation under contract to Mitsubishi (Nippon Electric developed part of the CS communication subsystem and all of the CS2 communication subsystem)
Operated by	NASDA

[a]CS.
[b]CS2.
[c]See Figures 7-62 and 7-64 for specific frequencies.

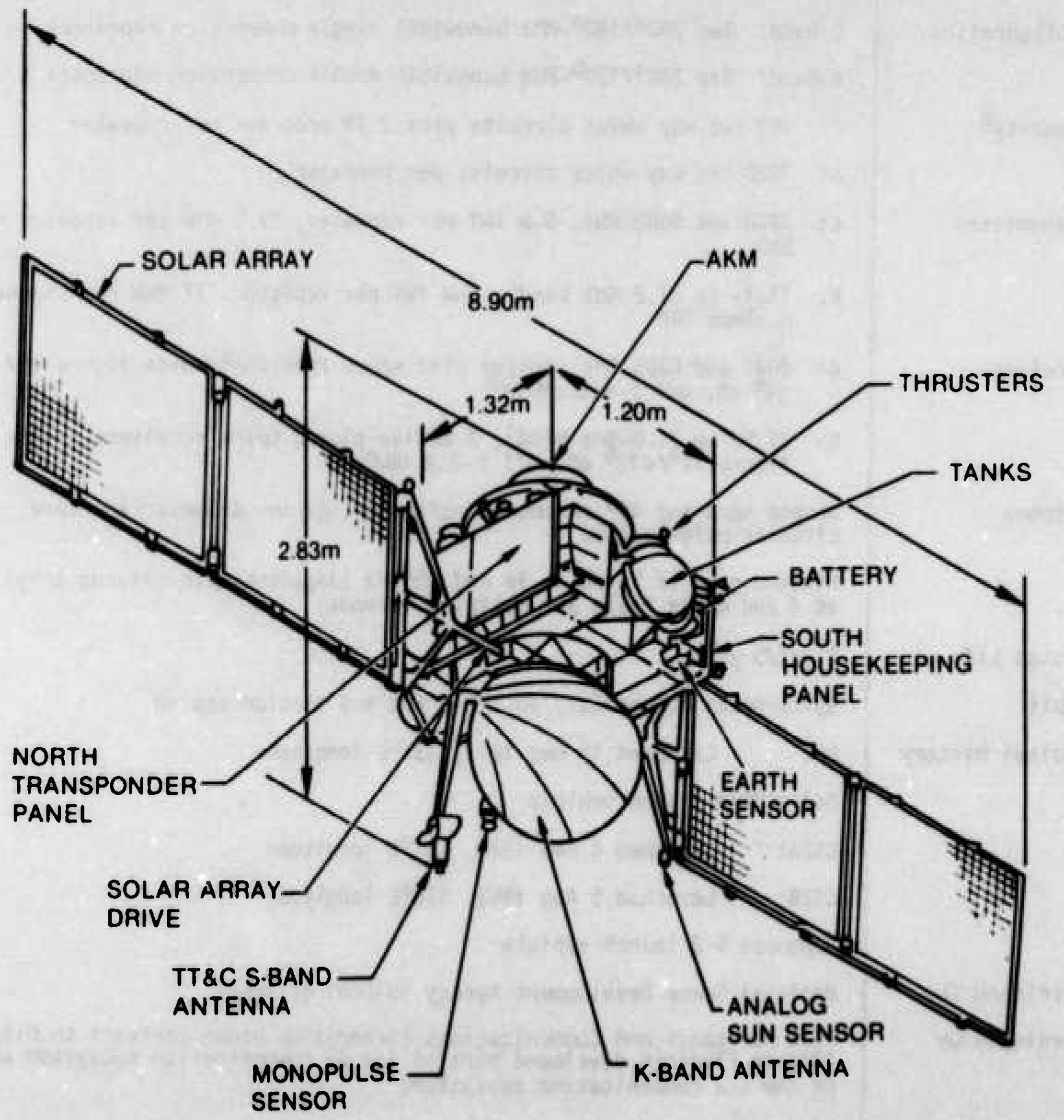
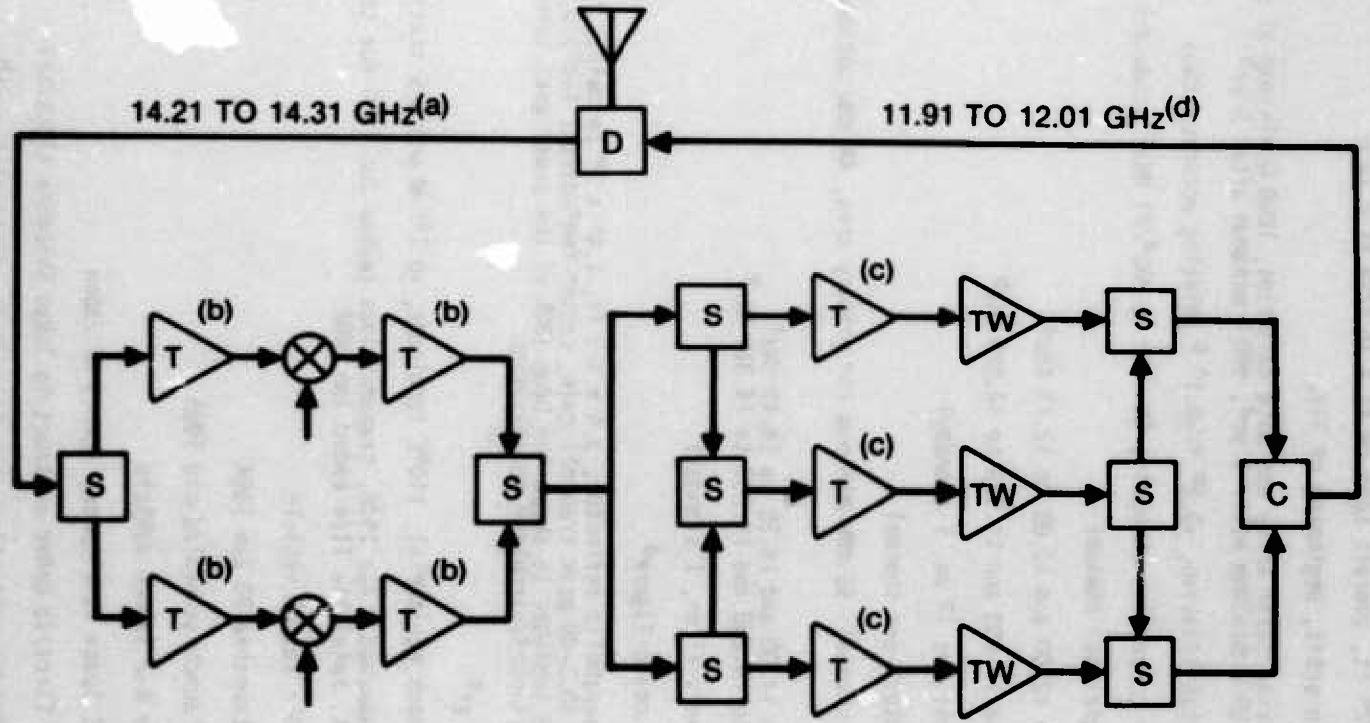


Figure 7-65. Japanese Broadcasting Satellite (BS2)



(a) 14.25 to 14.43 in BSE
(b) TD in BSE
(c) TW in BSE
(d) 11.95 to 12.13 in BSE

Figure 7-66. Broadcasting Satellite Communication Subsystem (BS2)

Table 7-34. Broadcasting Satellite Details

Satellite	Rectangular body, ~4 ft square, overall depth (body and antenna) 10[a]/9-1/2[b] ft, overall span 29 ft 4 in.[a]/29 ft 2 in.[b]
	780 lb in orbit, beginning of life
	Sun tracking solar array and NiCd batteries, 1000 W minimum at beginning of life[a], 780 W minimum after 3 yr[a], 900 W minimum after 5 yr[b]
	3-axis stabilization, $\pm 0.2^{\circ}$ [a]/$\pm 0.1^{\circ}$ [b] pointing accuracy (3σ)
Configuration	2 single conversion channels, 50- and 80-MHz[a]/27 MHz[b] bandwidth
Capacity	1 TV signal per channel
Transmitter	11.95 to 12.00 and 12.05 to 12.13 GHz[a]
	11.906 to 11.933 and 11.983 to 12.010 GHz[b]
	3 transmitters (2 on, 1 standby)
	100-W output per channel
	ERP per channel: 55 dBW minimum for primary area, 46 dBW minimum for fringe areas
Receiver	14.25 to 14.30 and 14.35 to 14.43 GHz[a] 14.206 to 14.233 and 14.283 to 14.310 GHz[b]
	2 receivers (1 on, 1 standby)
	$\leq$8.5 dB noise figure[a]
Antennas	Single parabolic reflector, 3.4 x 5.2 ft, $1.4^{\circ} \times 2^{\circ}$ beamwidth (at -4 dB), 40.3-dB peak transmit gain, center fed[a]/offset fed[b]; 3 feeds are used together to shape the beam (80% of the power goes through the main feed); linear[a]/circular[b] polarization
Design Life	3 yr[a]/5 yr[b]
Orbit	Synchronous equatorial, 110°E longitude, $\pm 0.1^{\circ}$E-W and N-S stationkeeping
Orbital History	BSE: Launched 7 Apr 1978, transmissions ceased Jun 1980 due to TWT failures, satellite life ended Jan 1982.
	Delta 2914 launch vehicle
	BS2A: Launched 23 Jan 1984
	BS2B: Launch scheduled mid 1985
	Japanese N-2 launch vehicle
Developed for	National Space Development Agency of Japan
Developed by	General Electric under contract to Tokyo Shibaura (Toshiba)
Operated by	NASDA[a]/Telecommunications Satellite Corp. (Telesat-Japan)[b]

[a]BSE.
[b]BS2.

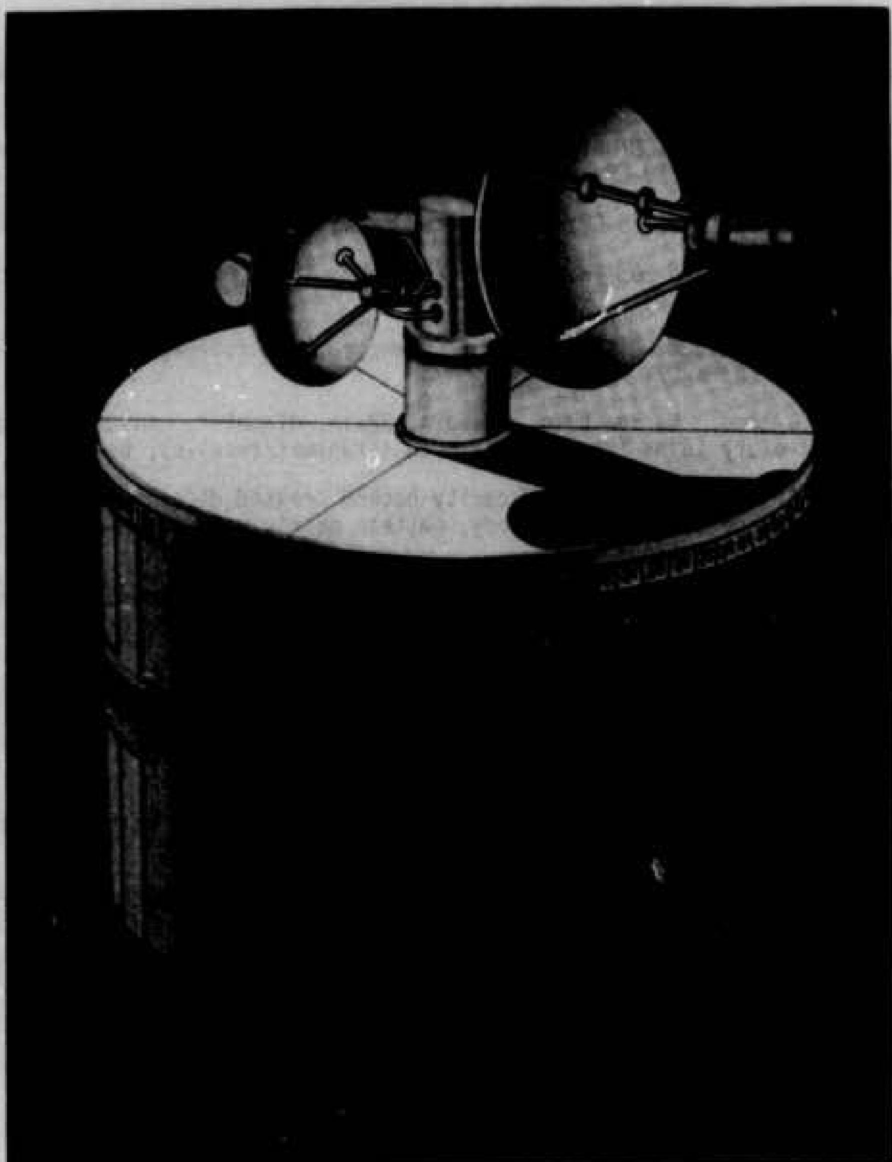


Figure 7-67. Japanese Experimental Communications Satellite

Table 7-35. Japanese ECS Details

Satellite	Cylinder, 55.7-in. diameter, 37 in. high, overall height 64.8 in.
	~290 lb in orbit, beginning of life
	Solar cells and NiCd batteries, 118 W maximum at beginning of life, 99 W minimum after 1 yr
	Spin-stabilized, 80 to 115 rpm
Configuration	Single transponder with selectable bandwidth of 10, 40, or 120 MHz, input and output independently switchable to other C-band or K-band
Transmitter	C-band: 4.08-GHz center frequency; redundant 5-W TWTs (one on, one standby); 23-dBW ERP
	K-band: 31.65-GHz center frequency; single 2.5-W TWT; 34-dBW ERP
Receiver	C-band: 6.305-GHz center frequency; tunnel diode preamplifier; -12 dB/^{o}K G/T
	K-band: 34.83-GHz center frequency; mixer followed by transistor amplifier; -5 dB/^{o}K G/T
Antennas	C-band: Narrow beam parabola, 22-in. diameter, measured minimum gain with rotary joint loss 20.5/23.6 dB (transmit/receive), beamwidth ~9/6.5^{o}
	Array composed of 128 cavity-backed crossed dipoles mounted in a band around the satellite body, pattern nearly uniform in array plane and $\pm 45^{o}$ from the plane
	K-band: Narrow beam parabola, 12-in. diameter, measured minimum gain with rotary joint loss 34.7/34.9 dB (transmit/receive), beamwidth ~2.5^{o}
	All antennas use circular polarization
	The 2 narrow beam antennas are despun together
Design Life	~1-1/2 yr
Orbit	Synchronous equatorial, 145^{o}E longitude planned, both satellites actually are drifting in near synchronous elliptical orbit
	A: Launched 6 Feb 1979, destroyed by collision with launch vehicle third stage during apogee motor firing
	B: Launched 22 Feb 1980, destroyed by apogee motor failure
	Japanese N launch vehicle
Developed for	National Space Development Agency of Japan
Developed by	Mitsubishi (prime)
	Ford Aerospace and Communications Corporation (spacecraft and antennas)
	Nippon Electric company (transponder)

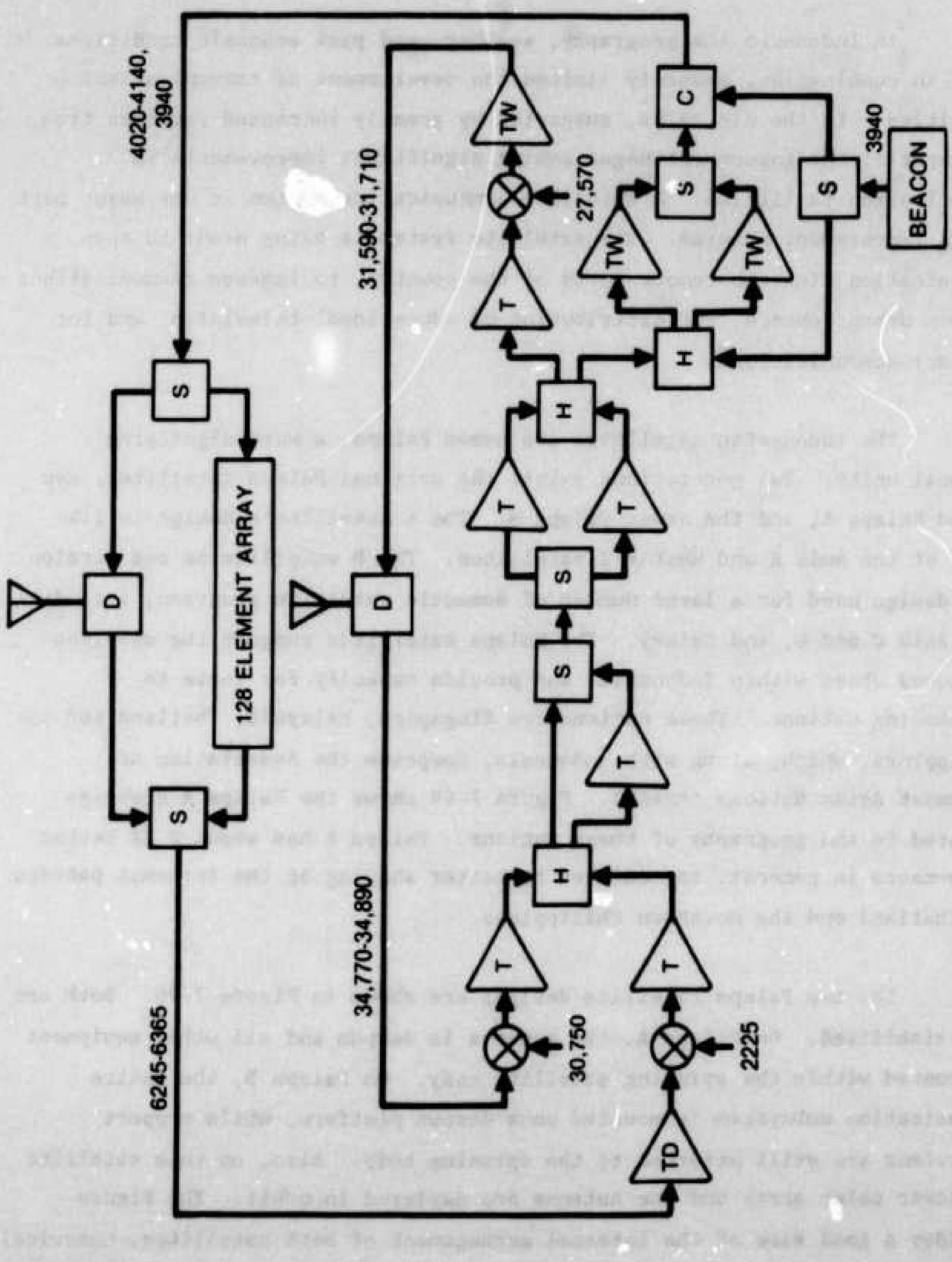


Figure 7-68. Japanese ECS Communication Subsystem

7.13 INDONESIA (PALAPA) (Refs. 697-706)

In Indonesia the geography, weather, and past economic conditions have, in combination, severely limited the development of communications facilities. In the mid 1970s, supported by greatly increased revenues from oil exports, the government began making significant improvements in communication facilities. A satellite communication system is one major part of the improvement program. The satellite system is being used: to open communication links to remote parts of the country, to improve communications between urban centers, for distribution of educational television, and for military communications.

The Indonesian satellites are named Palapa, a word signifying national unity. Two generations exist: the original Palapa satellites, now called Palapa A, and the newer Palapa B. The A satellite's design is like those of the Anik A and Westar I satellites. The B satellite is one version of a design used for a large number of domestic satellite programs, including SBS, Anik C and D, and Galaxy. The Palapa satellites support the services mentioned above within Indonesia, and provide capacity for lease to neighboring nations. These nations are Singapore, Malaysia, Thailand and the Philippines, which, along with Indonesia, comprise the Association of Southeast Asian Nations (ASEAN). Figure 7-69 shows the Palapa A coverage compared to the geography of these nations. Palapa B has about 2 dB better performance in general, in addition to better shaping of the transmit pattern for Thailand and the northern Philippines.

The two Palapa satellite designs are shown in Figure 7-70. Both are spin-stabilized. On Palapa A, the antenna is despun and all other equipment is mounted within the spinning satellite body. On Palapa B, the entire communication subsystem is mounted on a despun platform, while support subsystems are still attached to the spinning body. Also, on this satellite the lower solar array and the antenna are deployed in orbit. The Figure provides a good view of the internal arrangement of both satellites; numerical details are given in Table 7-36.

The Palapa A communication subsystem has 12 channels. Redundant wideband receivers are followed by 12 nonredundant channelized transmitters. The Palapa B communication subsystem (Figure 7-71) has 24 channels. The equipment is basically double that of Palapa A, with each set of 12 channels received and transmitted on separate polarizations. Also, some transmitter redundancy is provided, and the transmitter output power has been doubled.

The Palapa A satellites were launched in 1976 and 1977. They are currently projected to last until 1985 and 1986, two years beyond their design lifetime. The first Palapa B was launched in June 1983, and will take some traffic from the A satellites, in addition to supporting new services. The second B satellite was be launched in February 1984, but was left in a low orbit by a malfunction of the perigee motor.

The Palapa system began operations in August 1976 on the date of the 31st anniversary of Indonesian independence. Forty ground terminal were in use then, with ten more added in 1978. By 1981 the number of terminals was up to 120, with the total expected to grow to about 300 in the coming years. Transmission techniques include FDM/FM trunk telephone links, SCPC thin route telephony and telegraphy, and FM television. The SCPC links are split between preassignment and demand assignment. Equipment is being developed for use of TDMA in a few channels to increase channel capacity. Also, a low rate digital packet transmission network is in development and the use of video conferencing is being studied. The Philippines, Thailand, and Malaysia are all using leased capacity for their internal communications.

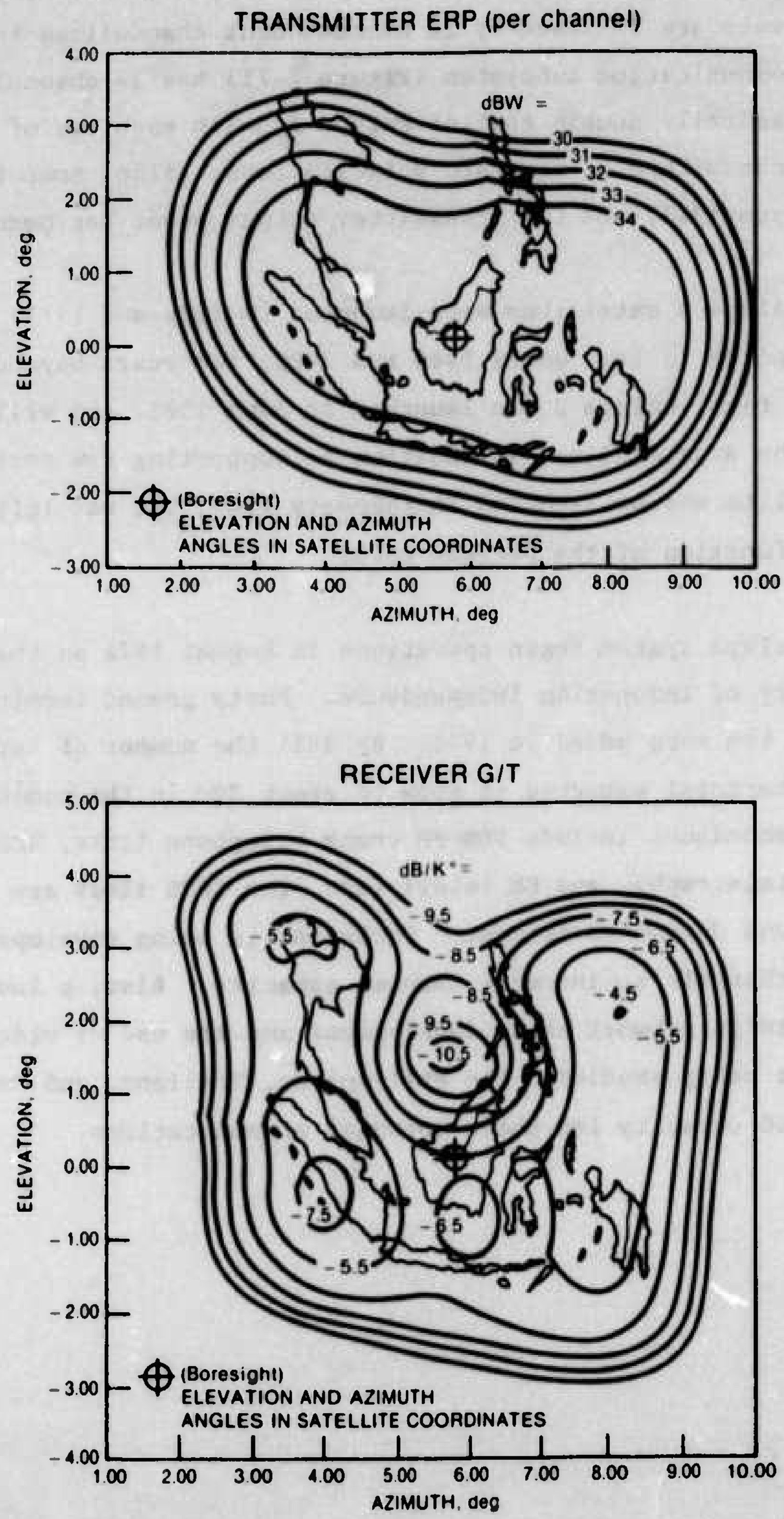
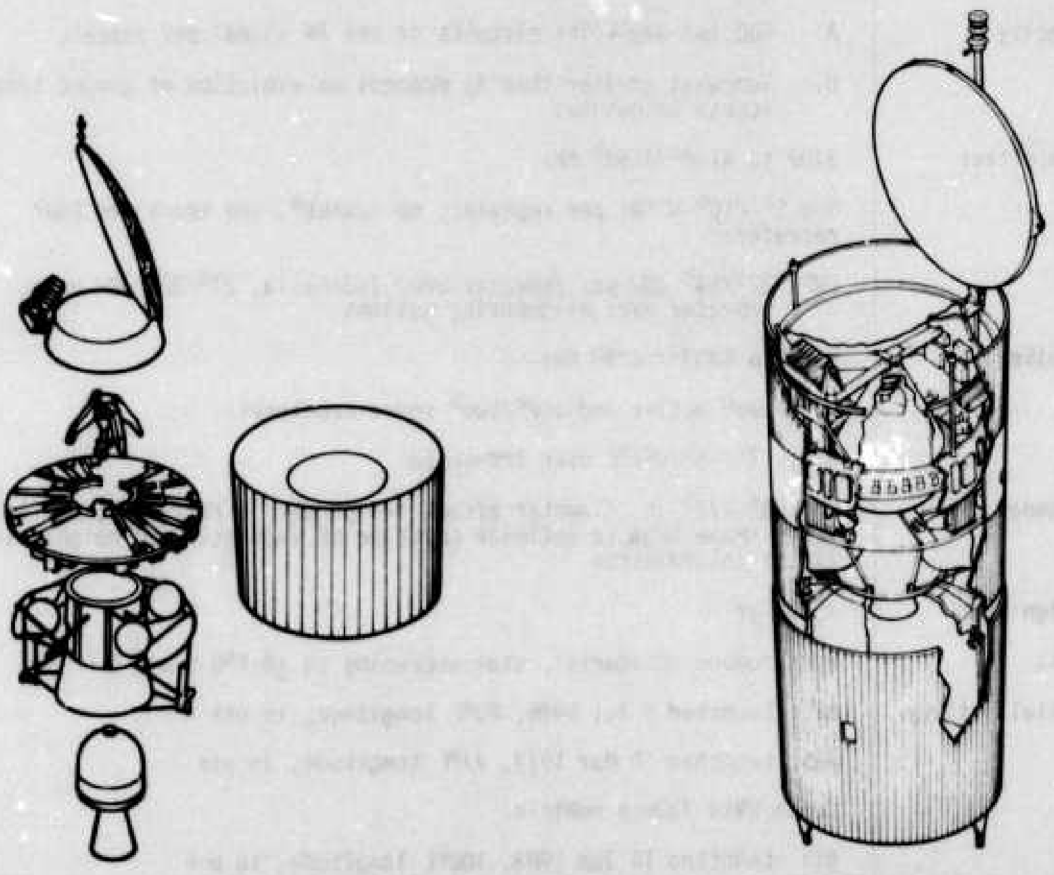


Figure 7-69. Palapa Antenna Pattern



a. PALAPA A b. PALAPA B

Figure 7-70. Palapa Satellites

Table 7-36. Palapa Details

Satellite	A: Cylinder, 75-in. diameter; overall height 139 in. B: Cylinder, 85-in. diameter; 108 in. tall in launch condition; 269 in. (22 ft 5 in.) tall deployed 670[a]/1385[b] lb in orbit, beginning of life Solar cells and NiCd batteries, 300[a]/~1000[b] W beginning of life, ~240[a]/~830[b] W end of life Spin-stabilized, ~90[a]/60[b] rpm, gyrostat[b], antenna pointing to $\pm 0.1^{\circ}$ or better
Configuration	A: Twelve 36-MHz bandwidth single conversion repeaters B: Twenty-four 36-MHz bandwidth single conversion repeaters, dual polarization frequency reuse.
Capacity	A: 600 two-way voice circuits or one TV signal per repeater B: Somewhat greater than A; depends on evolution of ground terminals and access techniques
Transmitter	3702 to 4178[a]/4198[b] MHz One 5[a]-/10[b]-W TWT per repeater; no spares[a], one spare per four repeaters[b] ERP: 32[a]/34[b] dBW per repeater over Indonesia, 27[a]/32[b] dBW per repeater over neighboring nations
Receiver	5927 to 6403[a]/6423[b] MHz One[a]/two[b] active and one[a]/two[b] spare receivers G/T: -7[a]/-5[b] dB/°K over Indonesia
Antenna	One 60[a]-/72[b]-in. diameter offset fed parabolic reflector, multiple feeds shape beam to optimize coverage of Indonesia and neighboring nations, linear polarization
Design Life	7[a]/8[b] yr
Orbit	Synchronous equatorial, stationkeeping to $\pm 0.1^{\circ}$N-S and E-W
Orbital History	A1: Launched 8 Jul 1976, 83°E longitude, in use A2: Launched 10 Mar 1977, 77°E longitude, in use Delta 2914 launch vehicle B1: Launched 18 Jun 1983, 108°E longitude, in use B2: Launched 6 Feb 1984, PAM failure Shuttle/PAM-D launch vehicle
Developed for	Perumtel (Perusahan Umum Telekomunikasi), the Indonesian government communications agency
Developed by	Hughes Aircraft Company
Operated by	Perumtel

[a]Satellites A1 and A2
[b]Satellites B1 and B2

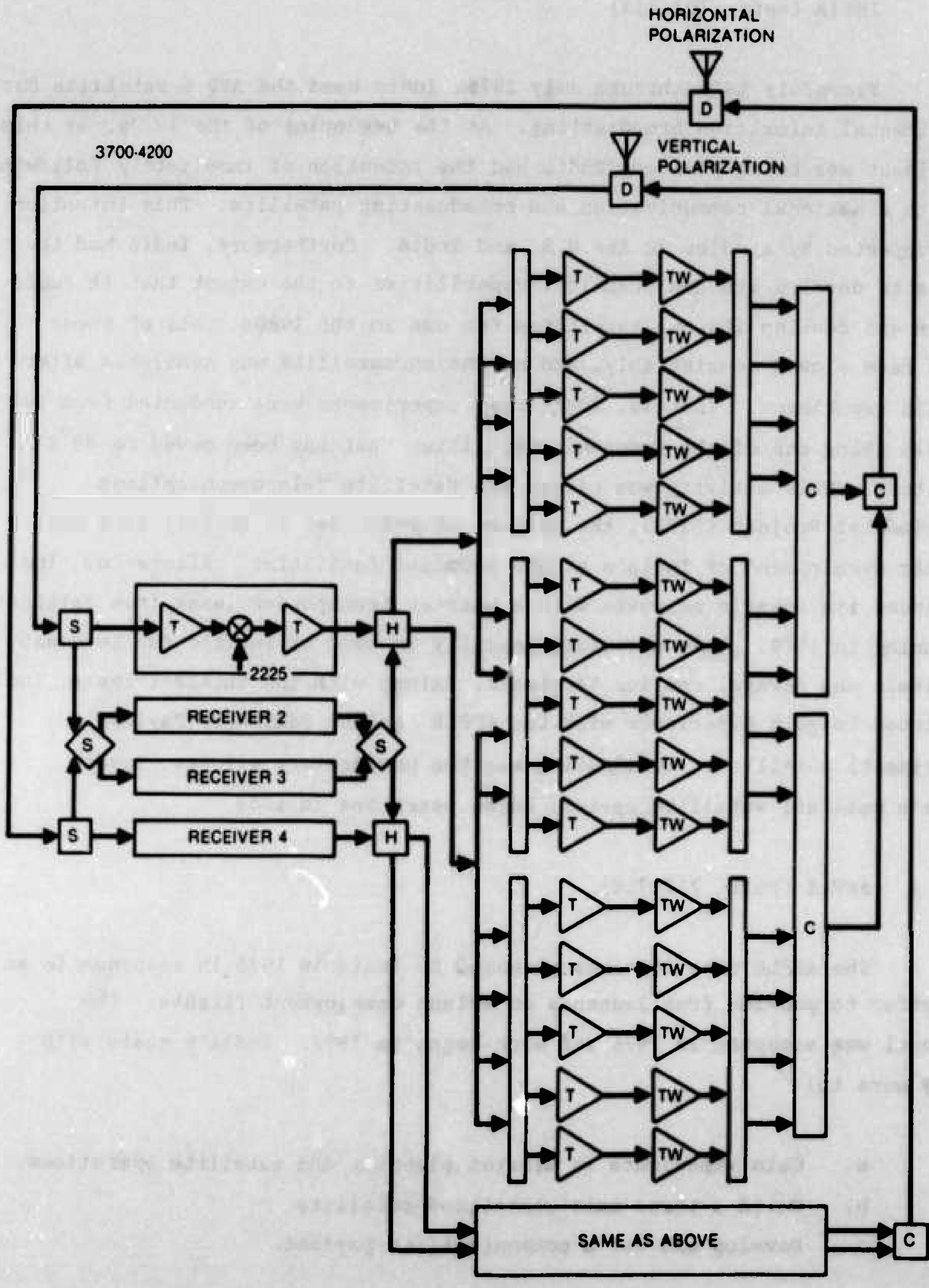


Figure 7-71. Palapa B Communication Subsystem

7.14 INDIA (Refs. 707-713)

From July 1975 through July 1976, India used the ATS 6 satellite for experimental television broadcasting. At the beginning of the 1970s, as this experiment was being planned, India had the intention of immediately following it with a national communication and broadcasting satellite. This intention was supported by studies in the U.S. and India. Furthermore, India had the desire to develop its own technical capabilities to the extent that it could design and develop its own satellites for use in the 1980s. All of these plans have slowed considerably, and no Indian satellite was available after the ATS experiment. Instead, additional experiments were conducted from 1977 to 1979 using one of the Symphonie satellites that has been moved to 49°E longitude. This activity was called the Satellite Telecommunications Experimental Project (STEP), the purpose of which was to collect data for further development of India's ground terminal facilities. Afterwards, India continued its interim measures with a quarter transponder lease from Intelsat beginning in 1979. This satellite capacity is used by India's two Intelsat terminals and several smaller terminals. Along with the Intelsat lease, India continued to gain experience with the APPLE (Ariane Passenger Payload Experiment) satellite. Culminating all the preparatory efforts, Insat, India's national satellite system, began operating in 1982.

7.14.1 APPLE (Refs. 712-715)

The APPLE satellite was proposed by India in 1975 in response to an ESA offer to provide free launches on Ariane development flights. The proposal was accepted in 1976 and work began in 1977. India's goals with APPLE were to:

a. Gain experience in mission planning and satellite operations.

b. Build a three-axis-stabilized satellite.

c. Develop and use a communications payload.

The APPLE program was managed by the Indian Space Research Organization (ISRO), which is a part of the national government's Department of Space.

ISRO designed the APPLE satellite and assembled it, using items manufactured by ISRO and by contractors in India, France, Germany, and the United States. The satellite (Figure 7-72) is composed of a cylindrical structure, two internal equipment shelves, and two solar panels. The payload is a single, redundant, communications transponder which uses the antenna mounted on the front end of the cylinder. Table 7-37 provides additional information.

APPLE was launched in June 1981. ISRO took control of it beginning with the transfer orbit. After injection into synchronous orbit, one of the solar panels could not be deployed. This cut the available power by one half and also caused thermal problems. Nevertheless, techniques were developed that allowed use of the satellite throughout its two-year design life.

7.14.2 Insat (Refs. 711-713, 716-721)

Insat is India's first operational satellite. It has both communications and meteorological payloads. The uses of Insat are:

a. To supplement terrestrial communication facilities on major interurban links.

b. To provide reliable communications to areas isolated by difficult terrain.

c. To provide television broadcasting to rural areas for educational and agricultural programs.

d. To collect satellite imaging and terrestrial data for weather forecasting.

The first two objectives are accomplished with a 12- transponder payload which uses the 4- and 6-GHz frequency bands. Its design, with

redundant wideband receivers and channelized transmitters, is relatively simple. The only unusual feature is the interconnection with other payloads. The broadcasting payload satisfies the third objective. It has two transponders which have 6-GHz uplinks and 2.5-GHz downlinks. Both share antennas with the communications payload.

The weather forecasting objective requires two payloads. One is a visible light and infrared radiometer on the satellite which transmits images of the earth. Resolution is 2.75 km in visible light and 11 km in infrared. One complete image, covering a 20 deg square field at the satellite, is collected and transmitted in 23 minutes. After seven minutes, another image is started. The data relay payload receives brief transmissions from many data collection platforms at about 400 MHz and retransmits them to a central site at about 4 GHz. The platforms are both on land and the ocean and collect meteorological and hydrological data. Both the radiometer and data relay downlinks use the antennas of the other payloads. The connections between all four payloads are shown in Figure 7-73. Details are in Table 7-38.

The Insat communications payloads are used primarily for telephony. Typically, one transponder will be used for television program distribution. Large and medium size terminals used FDM/FM/FDMA transmissions for multichannel links. Small terminals, handling fewer circuits, use SCPC/FDMA. The broadcast payload accommodates one television program and several voice circuits per transponder. All can be received by community terminals with 12-ft diameter antennas constructed of wire mesh. It is planned that 8000 of these be in use with Insat. The voice circuits are radio broadcasts and a disaster warning channel. The transmission rate for the radiometer data is 400 kbps; the data collection platforms transmit at 4.8 kbps. Both use PSK.

Figure 7-74 is a picture of the satellite. The antennas deployed from opposite sides of the body handle all receiving and transmitting functions except for uplinks from the data collection platforms. The feed horns for the rectangular reflector are on the edge opposite its deployment hinge. The circular items between them are the launch vehicle adaptor and

apogee motor nozzle. Data collection uplinks are received through the UHF antenna, which is the four rings on the earth-viewing face of the satellite. The solar array is only on one side of the satellite rather than consisting of two equal wings as on other three-axis-stabilized satellites. This is required so that the radiative cooler for the radiometer's infrared detectors, which is on the side opposite the solar array, has a clear view to deep space. The object on that same side of the satellite is a solar sail. The sail, by the geometry of its design and its separation from the satellite on a 30-ft deployable boom, will not interfere with the radiative cooler. The function of the sail is to counteract the torque caused by solar radiation pressure on the array.

All equipment is mounted within the satellite body. The apogee motor and in-orbit propulsion are combined in one bipropellant system. In-orbit thruster firings and rotation of the sun-tracking solar array are accomplished during the seven-minute periods when the radiometer is not active. During the 23-minute imaging cycle they are inhibited to improve attitude stability.

Insat 1A was launched in April 1982. After it reached geosynchronous orbit, one antenna deployed only after many attempts, and the sail never deployed. During a September 1982 attitude maneuver, the torque caused by the solar sail not being deployed resulted in the moon being in the field of view of the active earth sensor. The unpredicted moon interference caused the satellite attitude reference to be lost. Because the satellite command receiver was connected to the narrow coverage communications antenna rather than an omni antenna, the command link was broken as the satellite attitude changed. As a result, safing commands could not be received, all fuel was consumed, and the satellite was lost.

Insat 1B, with modifications to avoid the previous problems, was launched in August 1983. After initial problems with solar array deployment, it began orbital testing with all equipment acceptable. A few months earlier a contract was signed for production of Insat 1C which will be launched in 1986.

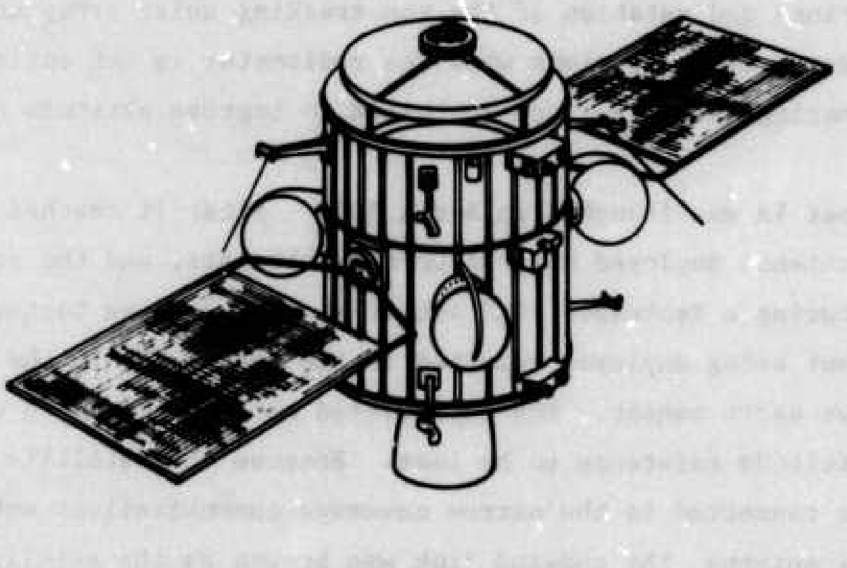
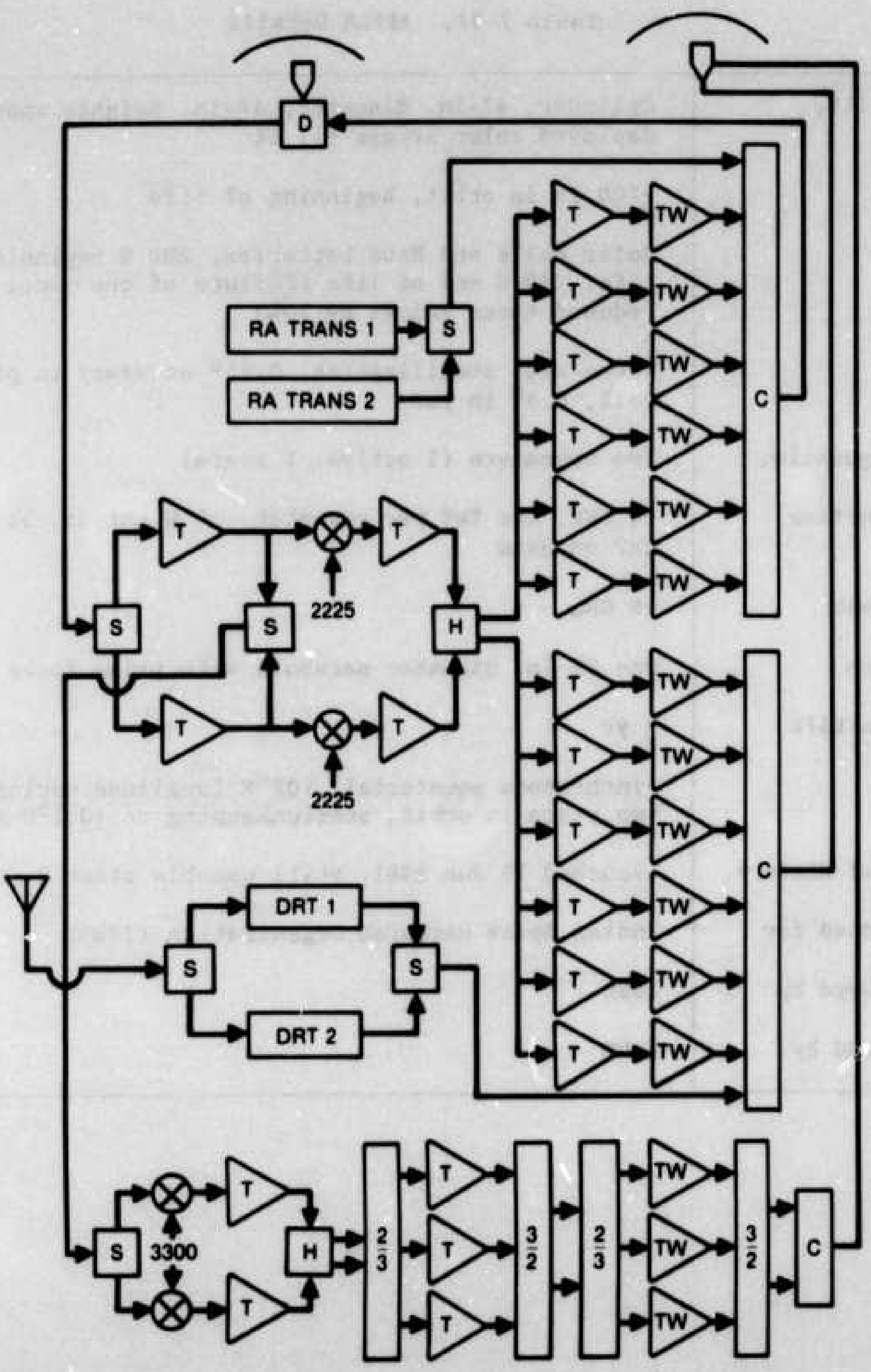


Figure 7-72. APPLE Satellite

Table 7-37. APPLE Details

Satellite	Cylinder, 47-in. diameter, 47-in. height; span of deployed solar arrays ~11 ft ~700 lb in orbit, beginning of life Solar cells and NiCd batteries, 280 W beginning of life, 210 W end of life (failure of one panel to deploy reduced these values by 50%) Three-axis stabilization, 0.25° accuracy in pitch and roll, 0.4° in yaw
Configuration	Two repeaters (1 active, 1 spare)
Transmitter	~4 GHz, one TWT per repeater, ~5 W output, 31.5 dBw ERP on axis
Receiver	~6 GHz
Antenna	One 35-in. diameter parabola with prime focus feed
Design Life	2 yr
Orbit	Synchronous equatorial, 102°E longitude during first two years in orbit, stationkeeping to ±0.1°N-S and E-W
Orbital History	Launched 19 Jun 1981, still useable after 2 yr in orbit
Developed for	Indian Space Research Organization (ISRO)
Developed by	ISRO
Operated by	ISRO



RA RADIOMETER
DRT DATA RELAY TRANSPONDER

Figure 7-73. Insat Communication Subsystem

Table 7-38. Insat Details

Satellite	Rectangular body 5.1 x 4.7 x 7.2 ft, N-S span of deployed solar array and solar sail 64 ft, E-W span of deployed antennas 19 ft.	
	~1230 lb in orbit, beginning of life	
	Solar cells and NiCd batteries, ~1200 W beginning of life, 900 W minimum after 7 yr, eclipse power for housekeeping, DR, RA and only four COM transponders	
	Three-axis stabilization, antenna pointing accuracy $\pm 0.2^{o}$ (pitch and roll), $\pm 0.4^{o}$ (yaw)	
Configuration	COM[a]:	Twelve 36-MHz bandwidth single conversion transponders
	BR[a]:	Two 36-MHz bandwidth single conversion transponders
	DR[a]:	One 200-kHz bandwidth transponder
	RA[a]:	400 kbps transmission of data from onboard radiometer
Capacity	COM:	Approximately 8000 two-way voice circuits plus one television program
	BR:	Two television programs
Transmitter	COM:	3712 to 4028 and 4042 to 4198 MHz
		One 4.5-W TWT per repeater, 32 dBW minimum ERP per repeater over primary coverage area[b] at end of life
	BR:	2557-2633 MHz
		One 50-W TWT per repeater plus one spare, 42 dBW minimum ERP per repeater over primary coverage area[b] at end of life
	DR:	4038.1 $\pm$0.1 MHz
		19 dBW minimum ERP at end of life
	RA:	4034.55 MHz
		8.5 dBW minimum ERP at end of life
Receiver	COM:	5937 to 6253 and 6267 to 6423 MHz
		Two receivers (one on one spare)
		G/T -6 dB/^{o}K minimum, -4.2 dB/^{o}K typical
		Two receivers (one on one spare)
	BR:	5857 to 5933 MHz
		Two receivers (one on, one spare)
		G/T set by and same as COM receiver
	DR:	402.75 $\pm$0.1 MHz
		Two receivers (one on, one spare)
		G/T -19dB/^{o}K

Table 7-38. Insat Details (Continued)

Antenna	COM & BR: One 54-in. diameter offset fed parabola for all reception and COM odd channels transmission, linear polarization, 4.5° beamwidth; one 60 x 63-in., offset fed parabola for COM even channels (linear polarization, 4.5° beamwidth) and BR transmission (LHCP); each has four feed horns DR: Array of four annular slot antennas, RHCP, 38° beamwidth for receive; COM antenna for transmit RA: COM antenna
Design Life	7 yr
Orbit	Synchronous equatorial, stationkeeping to ±0.1°N-S and E-W
Orbital History	1A: Launched 10 Apr 1982, died 4 Sep 1982, was at 74° E longitude Delta 3910/PAM launch vehicle 1B: Launched 30 Aug 1983, 74°E longitude, in use 1C: Launch scheduled in 1986, planned location is 94°E longitude Shuttle/PAM launch vehicle
Developed for	Indian Government Department of Space
Developed by	Ford Aerospace and Communications Corporation
Operated by	Department of Space

[a]Communications (COM), Broadcasting (BR), Data Relay (DR), Radiometer (RA).
[b]Primary coverage is about 80% of India; secondary coverage is some peripheral parts of India plus off-shore islands.

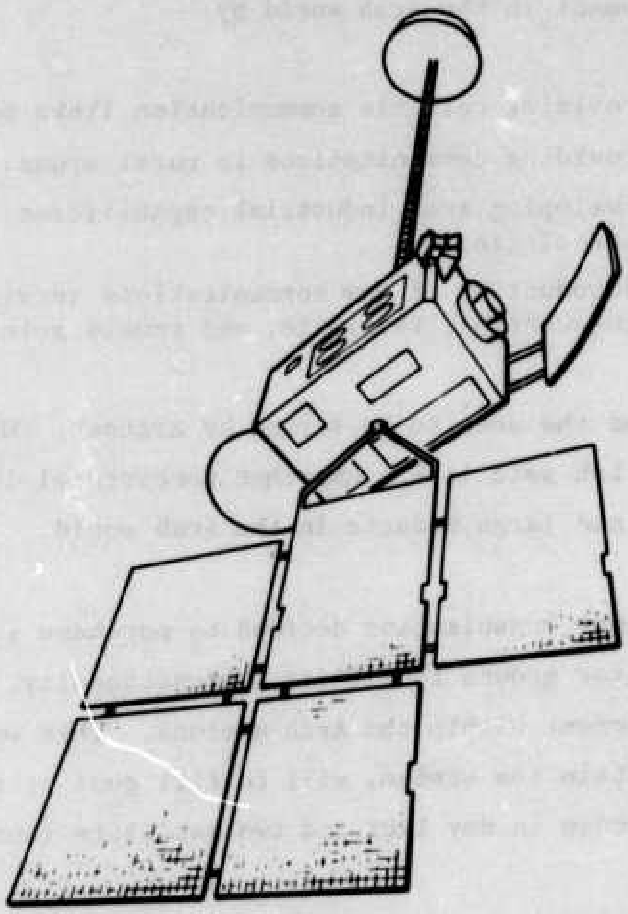


Figure 7-74. Insat Satellite

7.15 ARABSAT (Refs. 722-726)

The League of Arab States began considering a regional satellite communications system about 1970. In 1977 the Arab Satellite Communications Organization was formed, which now has 22 member nations. At its formation, technical and administrative committees began preparatory work for the Arabsat system. The purpose of the system is to promote economic, social, and cultural development in the Arab world by:

a. Providing reliable communication links between Arab states.

b. Providing communications in rural areas.

c. Developing Arab industrial capabilities in space-related technologies.

d. Introduction of new communications services such as video conferencing, facsimile, and remote printing of newspapers.

Figure 7-75 shows the area to be served by Arabsat. Within this area, it is easier to establish satellite links than terrestrial links because of the great distances and large deserts in the Arab world.

The Arabsat Organization decided to purchase satellites, launch services, and major ground facilities internationally, but to try to develop some ground equipment within the Arab nations. This work, plus training to operate and maintain the system, will fulfill goal c. above. The satellite contract was awarded in May 1981 and two satellite launches are scheduled in 1984.

The Arab satellite is being developed by a team of European and U.S. companies. It includes equipment used for other satellites, particularly Intelsat V and Telecom 1. It is a three-axis-stabilized design with solar arrays and antennas, which are deployed in orbit (Figure 7-76). The body is assembled in modules. The north, south, and earth-viewing faces hold the communication subsystem and thermal radiators. The other three faces hold support equipment and the two large antennas. A central cylinder is a

structural complement to the main rectangular structure, and contains the propulsion subsystem. Satellite details are given in Table 7-39.

Most Arabsat communications are in the 4- and 6-GHz frequency bands. The 6-GHz uplink consists of thirteen 33-MHz bandwidth channels spaced 37 MHz center-to-center on each of two polarizations. Twenty-five channels are retransmitted in the 4-GHz band. The other is transmitted at about 2.5 GHz, with a power level of about 80 W. This channel will be used for television transmissions to community reception terminals with 10-ft antennas, and will be used mainly for educational programs.

The 4/6-GHz channels will be used for telephony, telegraphy, low to medium speed data transmission, and distribution of television programs. Terminals in urban areas with 36-ft antennas will handle all these traffic types. Transmission techniques will be FDM/FM/FDMA for heavy route telephony, SCPC/FDMA for light route telephony and FM for television. Remote areas will have terminals with 15-ft antennas for television reception. Transportable terminals will be available for emergency communications.

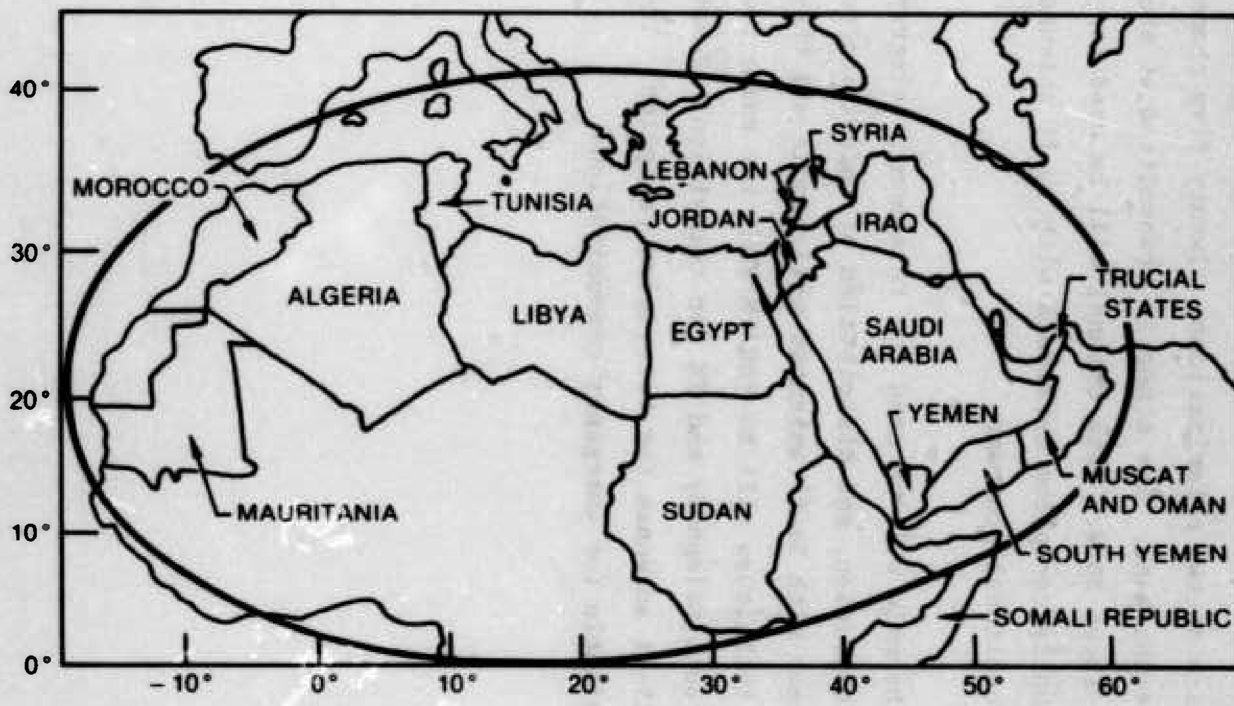


Figure 7-75. Arabsat Service Area

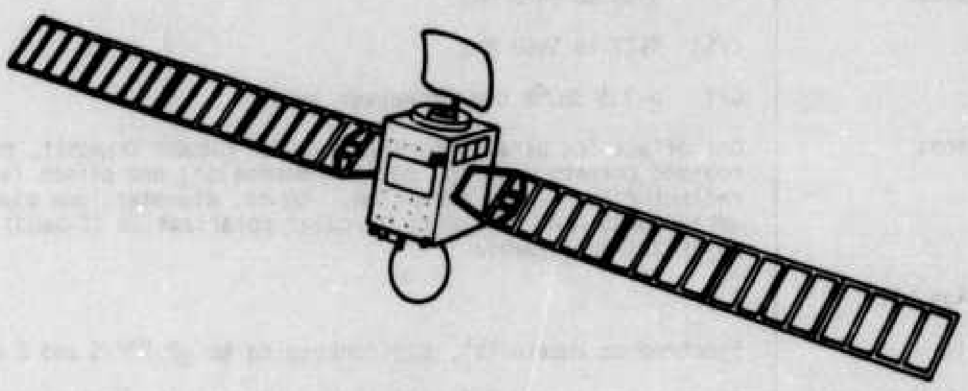


Figure 7-76. Arabsat Satellite

Table 7-39. Arabsat Details

Satellite	Rectangular body 87 x 60 x 63 in., east-west span with antennas deployed ~18-1/2 ft, span of deployed solar arrays 69 ft
	1500 lb in orbit, beginning of life
	Solar cells and batteries, 1300 W minimum at end of life
	Three-axis stabilization, $\pm 0.1^{o}$ antenna pointing accuracy
Configuration	C-band: Twenty-five 33-MHz bandwidth repeaters
	C/S-band: One 33-MHz bandwidth repeater
	Dual polarization frequency reuse in C-band
Capacity	C: 8000 voice circuits plus a few television signals
	C/S: One television signal
Transmitter	C: 3700 to 4198 MHz, 8.5 W output per repeater, 31 dBW minimum ERP per repeater at edge of coverage
	C/S: In 2540 to 2655 MHz band, ~80 W output via summing any two of three 50-W TWTs, 41 dBW minimum ERP at edge of coverage
Receiver	C: 5945 to 6423 MHz
	C/S: 5927 to 5960 MHz
	G/T $\geq$-7.5 dB/^{o}K over coverage area
Antenna	One offset fed parabolic reflector for C-band transmit, rectangular with rounded corners, ~80 in. maximum dimension; one offset fed parabolic reflector for C-band reception, ~60-in. diameter; one planar slotted array for S-band transmit; circular polarization (C-band), linear polarization (S-band)
Design Life	7 yr
Orbit	Synchronous equatorial, stationkeeping to $\pm 0.1^{o}$N-S and E-W
Orbital History	A: Launch scheduled fall 1984, will go to 19^{o}E longitude, Ariane launch vehicle
	B: Launch scheduled Oct 1984, will go to 26^{o}E longitude, Shuttle/PAM-D launch vehicle
Developed for	Arab Satellite Communications Organization (Arabsat)
Developed by	Aerospatiale
Operated by	Arabsat

7.16 AUSSAT (Refs. 94, 727-734)

In the large undeveloped and sparsely populated regions of Australia, means of communications and broadcasting are either unreliable or nonexistent. Satellite communications can provide the needed improvements at lower cost than terrestrial alternatives. The first study of an Australian domestic system was conducted in 1966. In 1969 Australia began routing some transcontinental telephone circuits through the Intelsat system. During 1970 experiments were conducted using ATS 1 to gather data that would be useful in planning a domestic satellite system.

Studies continued through the 1970s. In mid 1979 the government made a decision to implement a system. In fall 1979 the Canadian Hermes Satellite (CTS) was used for demonstrations of television broadcasting to small terminals at numerous locations. Distribution of television to 50 isolated communities began in 1980 using an Intelsat satellite. Satellite specifications were developed, a government-owned operating company (Aussat Proprietary Limited) was formed, and a satellite contract was signed between mid 1979 and April 1982.

The satellite design is basically the same as Anik C, Telstar 3, Galaxy, Palapa B, etc. It is a dual-spin satellite with a deployable solar array. Support subsystems are mounted on the spinning section and the communication subsystem is on a despun platform. The three dual-polarized reflectors are mounted on a common structure which is deployed in orbit. Figure 7-77 shows how the various sections of the satellite fit together.

Figure 7-78 shows the Aussat service areas: national, four spots which together cover the nation, and Papua New Guinea (PNG). There are transmit antenna beams for all six areas and receive antenna beams for national and PNG coverage. The two larger reflectors seen in Figure 7-77 are used for PNG and spot beams. The smallest reflector is used for national beams.

Aussat has 15 communications transponders, 11 low power and four high power. Because of the two types of transponders and the many antenna beams, the communication subsystem (Figure 7-79) has many switching matrices. The receivers all cover the entire 500-MHz uplink bandwidth, with one connected to each of the three antenna beams. The input switch for transponders 1 to 8 connects each transponder to either the national or PNG receiver output. The uplinks for these transponders use one polarization; the uplinks for transponders 9 to 15 use the other. The high power (30-W) transmitters and their redundancy switches are in the center of the diagram; the low power (12-W) transmitters are in the upper and lower parts of the diagram. Following the transmitters are the output switches which connect each transponder to one antenna beam. The transponders, with a bandwidth of 45 MHz, are spaced 64 MHz center-to-center in each polarization. This wide spacing was necessary to make the transponder switching and combining hardware practical. Satellite and communications details are given in Table 7-40.

The high power transponders will nominally each be connected to a different spot beam and will be used for broadcasting. Each will accommodate one television plus three radio programs. These broadcasts will be received at individual homes using 4-to 6-ft antennas. This service is primarily aimed at 1.3 million people who have poor quality or no broadcast reception. Terminals with 8-to 10-ft antennas will be adequate to provide single voice channels or low speed data. Larger terminals, with 15-to 20-ft antennas will be used for television distribution on low power transponders, multichannel voice, and medium speed data. These voice and data services will be for government, business, and private uses. The transmission technique will be SCPC/TDMA. Larger terminals will be used where traffic is high. Aussat will own one terminal in each of eight large cities through which it will provide a common carrier type service to users not needing a dedicated terminal. The transponders connected to the PNG antenna beams will be used for domestic telephony and broadcasting under the direction of the PNG government.

Three satellites are being built. Two will be launched in 1985 to begin the Aussat system. The third will be launched if there is a failure, or if traffic demand grows. Since considerable growth is being projected, the satellite contract includes an option for two more satellites. These may be needed by the end of the decade to provide adequate backup to the active satellites. Aussat will control all the satellites from an operations center in Sydney and TT&C sites in Sydney and Perth.

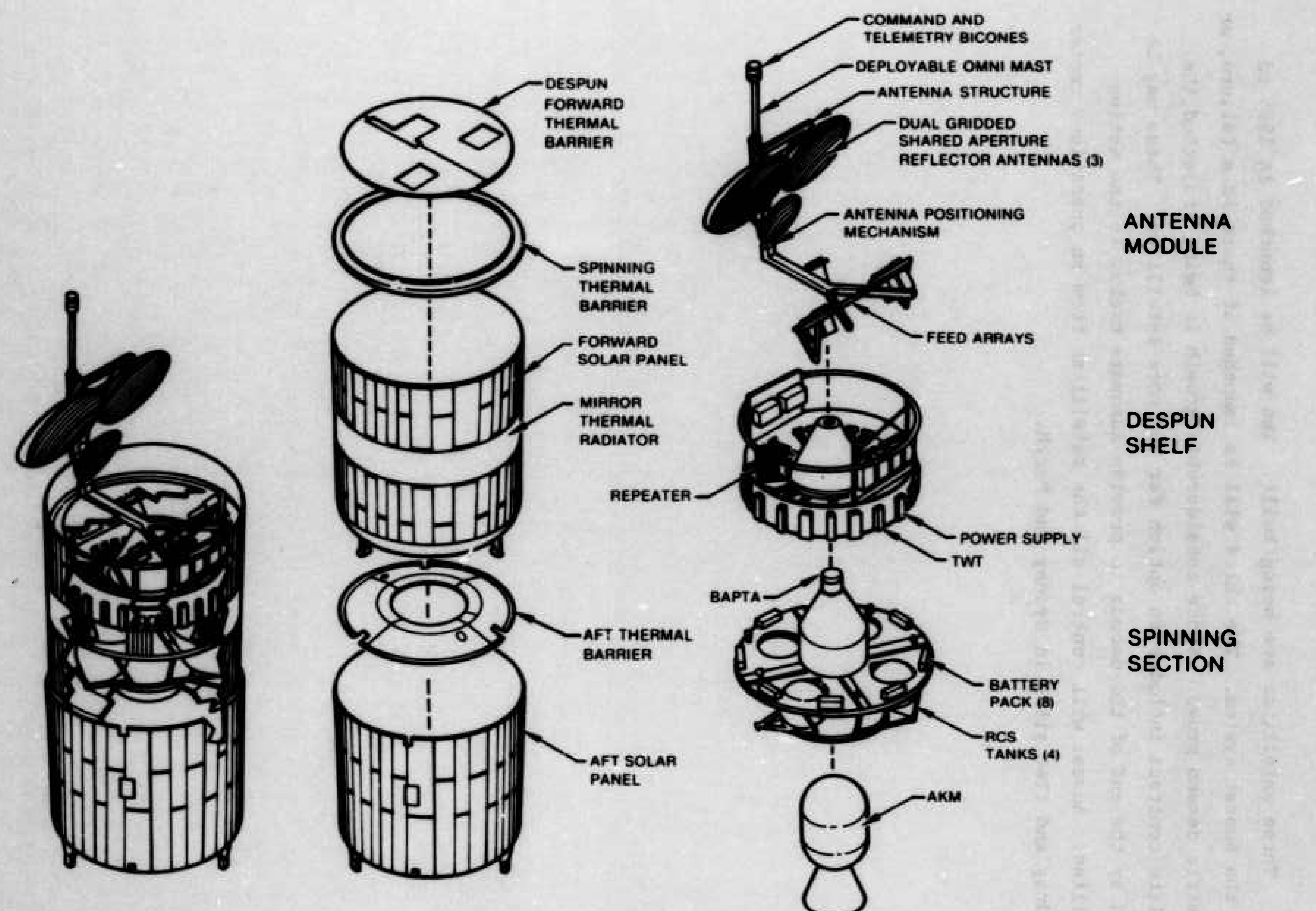


Figure 7-77. Aussat Satellite

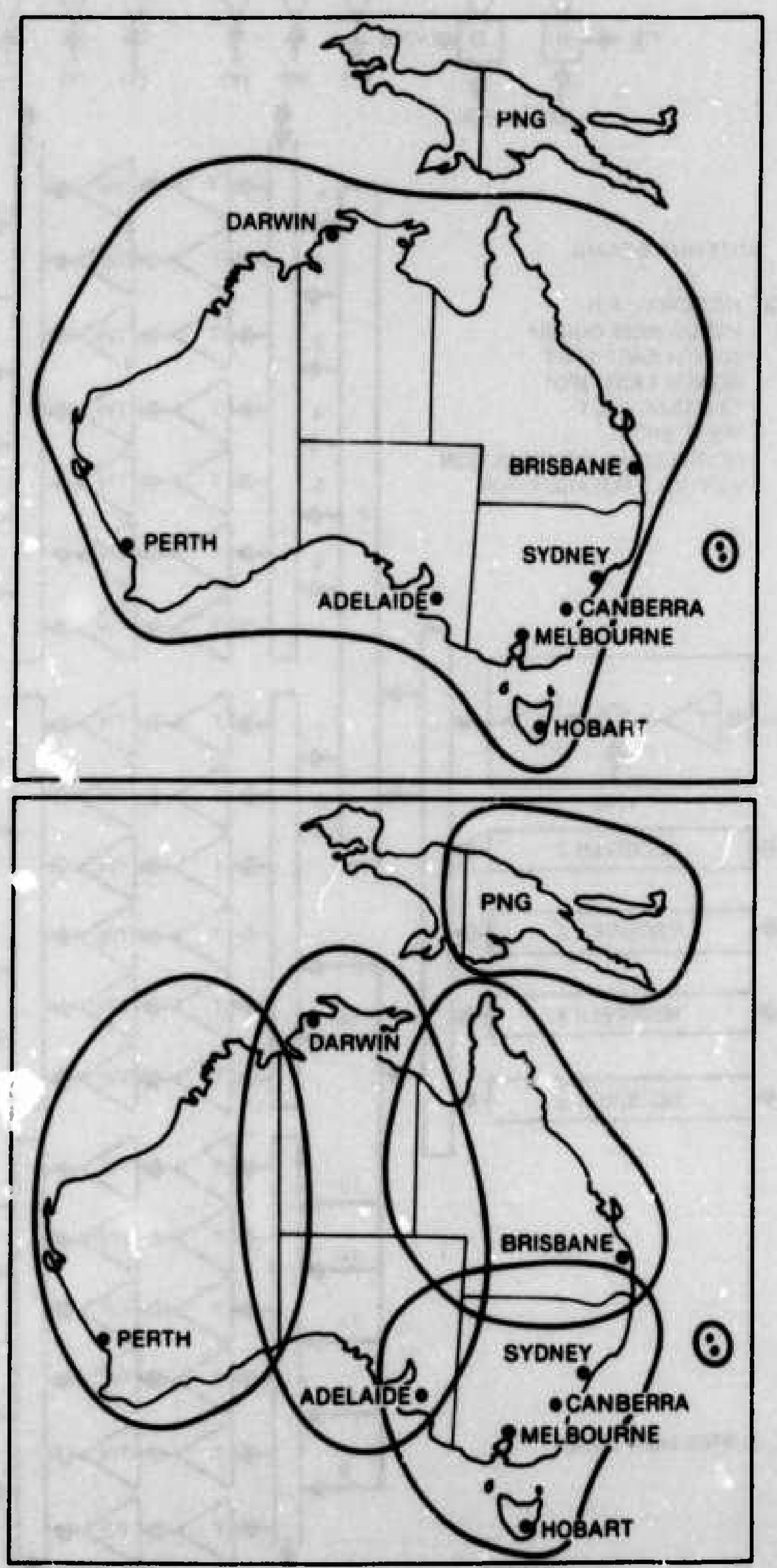


Figure 7-78. Aussat Service Areas

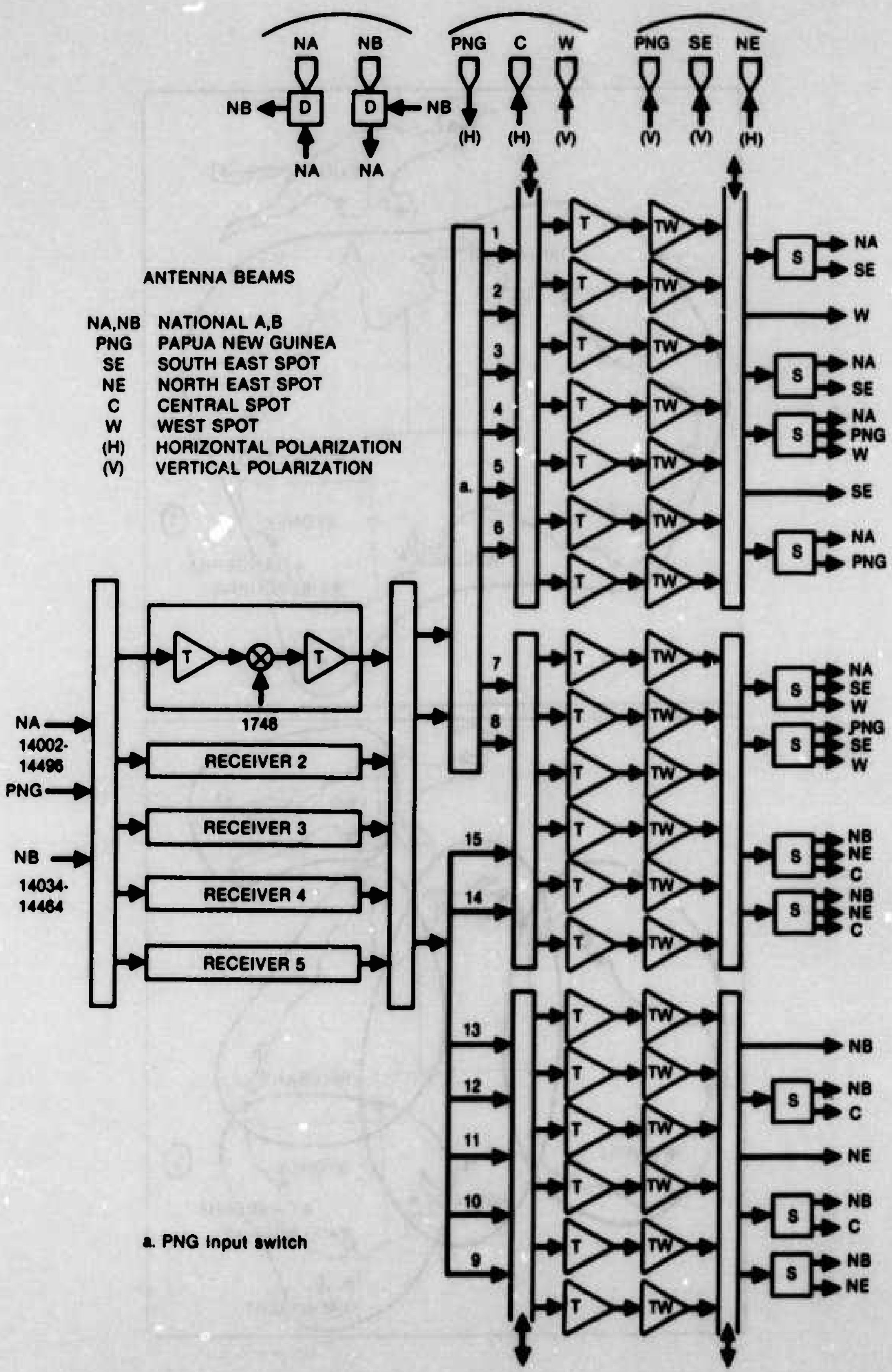


Figure 7-79. Aussat Communication Subsystem

Table 7-40. Aussat Details

Satellite	Cylinder, 85-in. diameter, 111 in. high stowed, 260 in. (21 ft 8 in.) high deployed
	1430 lb in orbit, beginning of life
	Solar cells and NiCd batteries, ~1050 W at beginning of life, ~840 W minimum at end of life
	Spin-stabilized, gyrostat, antenna pointing to $\pm 0.05^{\circ}$ or better
Configuration	Fifteen 45-MHz bandwidth single conversion repeaters, dual polarization frequency reuse
Transmitter	14.002 to 14.496 GHz
	11 active plus two spare transmitters with 12-W TWTs for repeaters 1 to 6 and 9 to 13
	4 active plus two spare transmitters with 30-W TWTs for repeaters 7, 8, 14, 15
	ERP per repeater at edge of coverage: 36/40 dBW in national beams, 41/45 dBW in Papua New Guinea beam, 43/47 dBW in spot beams (12/30 W TWT)
Receiver	12.254 to 12.748 GHz
	Three active plus two spare receivers
	G/T at edge of coverage: -3 dB/$^{\circ}$K in national beams, -1 dB/$^{\circ}$K in Papua New Guinea beam
Antenna	Three offset fed parabolic reflectors; one 24-in. diameter for national beams receive and transmit; one 39-in. diameter for Papua New Guinea beam and northeast and southeast spot beams transmit; one 43-in. diameter for Papua New Guinea beam receive and west and central spot beams transmit; all use linear polarizations; 32 dB minimum cross polarization isolation
Design Life	10 yr (fuel load for 7 yr min)
Orbit	Synchronous equatorial, stationkeeping to $\pm 0.05^{\circ}$N-S and E-W, 156°, 160° and 164°E longitude
Orbital History	1: Launch scheduled mid 1985
	2: Launch scheduled late 1985
	3: Launch tentatively scheduled for 1988
	Shuttle/PAM-D launch vehicle
Developed for	Aussat Proprietary Ltd., a government corporation
Developed by	Hughes Aircraft Co.
Operated by	Aussat Proprietary Ltd.

7.17 MEXICO (Refs. 735-736)

Mexico began domestic use of satellite communications in 1980, by leasing capacity on a Westar satellite. In 1983 Mexico switched to leased Intelsat capacity on a satellite moved to 53°W to provide domestic services for western hemisphere nations. In spring 1983 a contract was awarded for construction of a Mexican domestic communications satellite. This satellite, and the system of which it is a part, have at various times been called Mexsat, Satmex, Ilhuicahua and Morelos.

The satellite (Figure 7-80) shares the same design as many others, such as Anik C, SBS, Westar IV, Palapa B and Aussat. It is launched as a compact cylinder. In synchronous orbit the extra solar array, which surrounds the main body at launch, is deployed along three tracks mounted around its periphery. (The ends of two of the tracks are visible at the bottom of Figure 7-80.) Also, the antenna assembly is unfolded from its launch position against one end of the body. The antennas and their feed horns are attached to an equipment shelf upon which the communications electronics are mounted. This shelf is despun to maintain the proper east-west antenna pointing. North-south pointing is accomplished by a motor located at the hinge where the antenna assembly is attached to the satellite. Pointing information is obtained by tracking a 6-GHz beacon transmitted from the ground. Most of the equipment, other than the communications subsystem, is mounted to the spinning structure of the satellite.

Among all the satellites of this design, the Mexican satellite is the first to use two sets of communication frequencies. The larger antenna is for 4- and 6-GHz links, which use both linear polarizations. The smaller antenna is for 12- and 14-GHz links, which use only one polarization. Figure 7-81 shows the coverage provided by these antennas.

Most 4/6-GHz domestic communication satellites have 12 transponders using each polarization. In the Mexican satellite there are 12 transponders

on one polarization but only six on the other. The six have twice the bandwidth (72 MHz) of the 12 (36 MHz), so that the 4/6-GHz spectrum is fully used. Nevertheless, the reduction in 4/6-GHz transponders allows the satellite to carry an additional payload. This is four 108-MHz bandwidth 12/14-GHz transponders. This combination of transponders in two frequency bands maximizes the transponder bandwidth in this size satellite. The same approach is used by another manufacturer in the Spacenet and ASC satellites. Figure 7-82 is a diagram of this communication subsystem, and Table 7-41 provides additional design information.

The 4/6-GHz transponders will be used for telephony, business data transmissions, and television distribution. Ground terminals now in use with the Intelsat lease, and new terminals, will be used for these services. The 12/14-GHz transponders will be used for broadcasting educational television to small ground terminals.

Two satellites are being constructed. Both are scheduled to be launched in 1985. They will be controlled from a TT&C site to be built in central Mexico.

Figure 7-80. Mexican Satellite

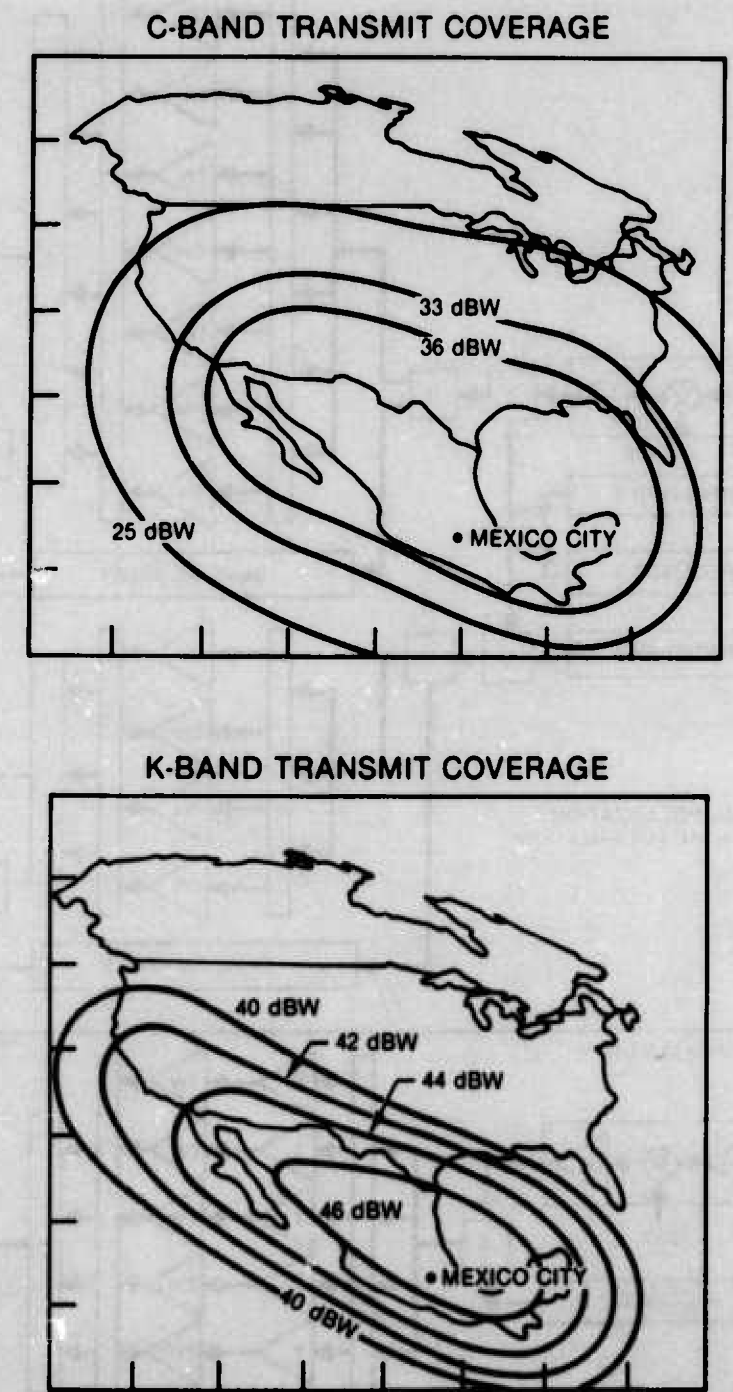


Figure 7-81. Mexican Satellite Coverage

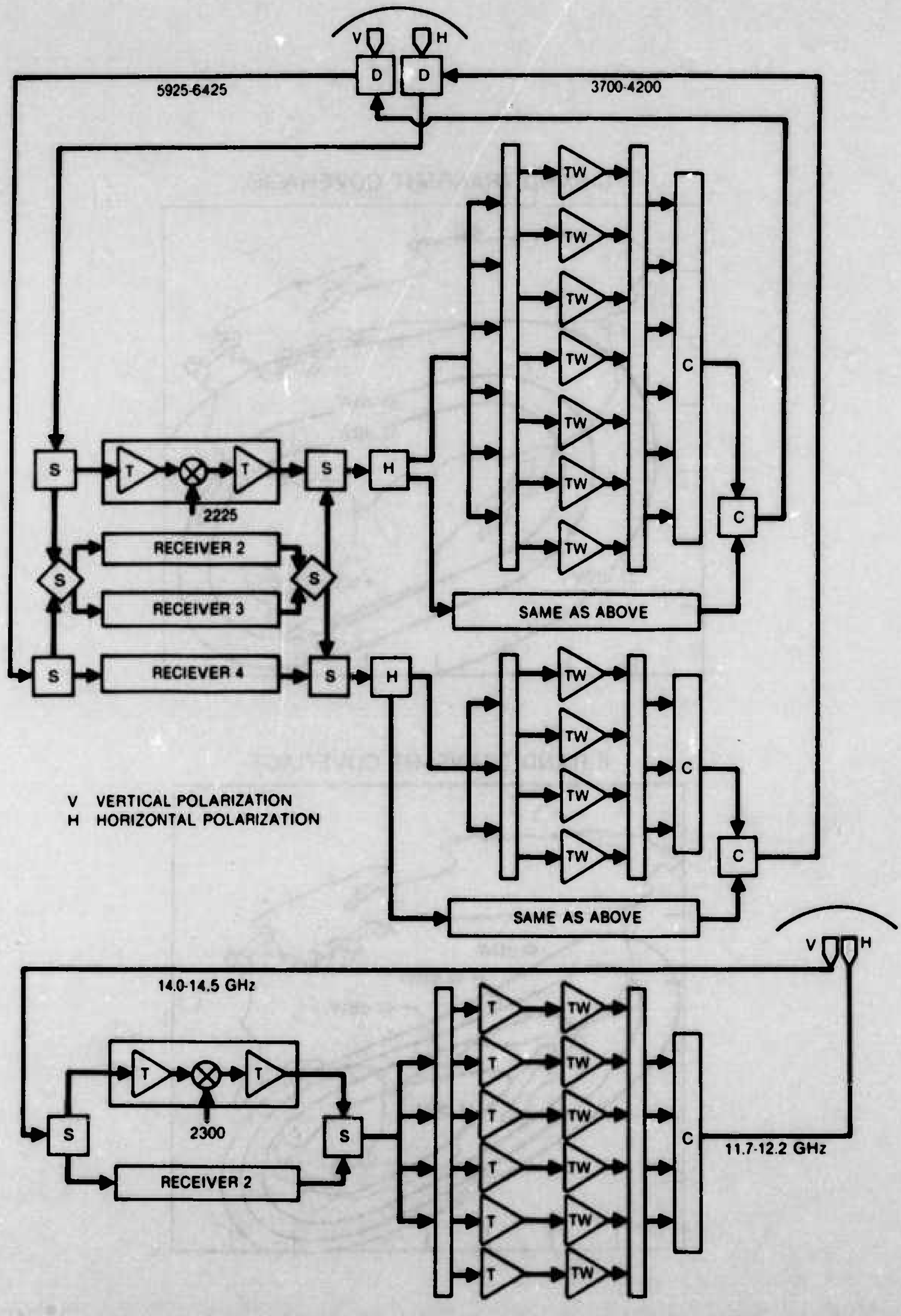


Figure 7-82. Mexican Satellite Communication Subsystem

Table 7-41. Mexican Satellite Details

Satellite	Cylinder, 85-in. diameter, 260 in. (21 ft-8 in.) tall when deployed ~1465 lb in orbit, beginning of life Solar cells and NiCd batteries, 940 W beginning of life, 760 W after 10 yr Spin-stabilized, gyrostat, ~60 rpm spin rate
Configuration	4/6 GHz: Twelve 36-MHz bandwidth single conversion repeaters and six 72-MHz bandwidth single conversion repeaters on orthogonal polarizations 12/14 GHz: Four 108-MHz bandwidth single conversion repeaters
Transmitter	4/6 GHz: 3700 to 4200 MHz Seven 7-W TWTs for each set of six 36-MHz repeaters, 36 dBW ERP per repeater at edge of coverage Eight 10.5-W TWTs for the six 72-MHz repeaters, 38 dBW ERP per repeater at edge of coverage 12/14 GHz: 11.7 to 12.2 GHz Six 20-W TWTs for the four repeaters, 44 dBW ERP per repeater at edge of coverage
Receiver	4/6 GHz: 5925 to 6425 MHz Four receivers (two on, two spare) 12/14 GHz: 14.0 to 14.5 GHz Two receivers (one on, one spare)
Antenna	4/6 GHz: One 71-in. diameter offset fed parabola with two polarization sensitive surfaces, multiple feed horns shape beam for Mexican coverage 12/14 GHz: One 36 x 59-in. diameter offset fed parabola with two polarization sensitive surfaces, multiple feed horns shape beam for Mexican coverage Linear polarization
Design Life	10 yr
Orbit	Synchronous equatorial, 113.5° and 116.5°W longitude, stationkeeping to $\pm$0.1° (or better) N-S and E-W
Orbital History	1: Launch scheduled May 1985 2: Launch scheduled Sep 1985 Shuttle/PAM launch vehicle
Developed for	Secretaria de Comunicaciones y Transportes
Developed by	Hughes Aircraft Company
Operated by	Secretaria de Comunicaciones y Transportes

7.18 BRAZIL (Ref. 737)

Satellites are the most practical means to improve communications through the large undeveloped parts of Brazil. In the early 1970s the country conducted some satellite communication experiments using ATS 3. An initial domestic system began in 1975 using a satellite transponder leased from Intelsat. A second transponder was leased in 1978, and a third in 1979. Another half transponder was added in 1980. In 1978 only six ground terminals were in use; by the end of 1982 the number had grown to about 40.

In 1975 the Brazilian government decided to have communication satellites built for its domestic system. Proposals were received the next year, but then the government delayed the project. Proposals were again received in late 1981. In summer 1982 a contract was signed for the development of two satellites, equipment for the control terminal, and training.

The satellites are very similar to the Anik D and Galaxy satellites. Much of the tabular data and drawings given in Sections 7.1 and 7.2 for those satellites should be applicable to the Brazilian satellites, which are called Brasilsat. Both are scheduled to be launched by Ariane in 1985.

7.19 INTELSAT LEASES (Refs. 210, 738-747)

The Intelsat Definitive Agreements, which came into force in February 1973, made provision for leasing satellite capacity for domestic systems. The Agreements state that Intelsat space segment capacity not required for the prime Intelsat objective (a global public network) shall be available for domestic services between areas separated by oceans or within areas not linked by terrestrial facilities where there are natural barriers that hinder the establishment of such facilities.

Interest in this use of Intelsat satellites was small for a few years, but began to grow rapidly in 1977. Many countries need to improve internal communications, and have situations well suited to the use of satellites. However, most do not have the finances necessary to obtain a satellite, nor enough traffic to warrant the use of a whole satellite. Leasing of satellite capacity has been the answer to these needs. At present, Intelsat provides almost all the leased capacity because of their many satellites and global deployment. Use of such a lease is a low cost way to establish a domestic satellite system. This arrangement also leads to a quick implementation, since ground terminals can be delivered much more quickly than satellites. Intelsat leases a specific bandwidth with certain guaranteed satellite performance parameters, G/T and ERP being the most significant. Subject to several constraints to prevent interference to other satellite users, the leasing country is free to control its own use of the leased capacity.

Prior to the availability of the Intelsat leases, some countries used the regular Intelsat service for domestic links, treating them as international links. An example was the use of Intelsat for links between CONUS and Hawaii, Alaska, and Puerto Rico. In February 1974 the U.S. transferred CONUS-Hawaii traffic to a leased transponder, which was the first use of an Intelsat lease. This lease was terminated in 1976 when the traffic was transferred to the AT&T domestic satellite.

Algeria was the first country to use an Intelsat lease for a nationwide system. Operations began in 1975 with 15 terminals, and greatly improved the availability and reliability of communications in the 80 percent of Algeria which lies in the Sahara desert. Three other countries began using Intelsat leases in 1975. Seven others had started by the end of 1977, and the number has grown since then as shown in Table 7-42.

The reasons for using an Intelsat lease are varied. Some countries use the satellite to open communications to undeveloped areas where it would be difficult to install terrestrial facilities. Examples are Algeria (desert) and Brazil (jungle). Other countries use the satellite to communicate with points separated by oceans. Examples are Columbia (off-shore island) and Norway (oil drilling platforms and Arctic islands). Some countries, such as Mexico, are using the Intelsat capacity as a step toward a national satellite system. An application which developed within the past year is for full time international television transmission. The first example is a link from the U.S. to Australia.

Intelsat currently leases space segment capacity in increments of one-quarter, one-half, or full transponders. The service is available on a preemptible or nonpreemptible basis, which relates to the priority of restoration in case of satellite failure. Nearly all the current leases are for preemptible service because of the proven reliability of the satellites (<1 hr outage/yr) and the lower cost (one-third the nonpreemptible rate). Actual leases are as small as one-quarter transponder and as large and three and one-half transponders. Several countries began with a lease of one transponder or less and added capacity over several years as they expanded their systems. Currently over 40 transponders are leased, and this number will grow to over 60 in 1985.

The leased capacity is used for television and radio broadcast distribution, telephony, and telegraphy. In some cases, only one type of traffic is used; in others it is a mix of several or all of these. With a transponder using earth coverage antennas and ground terminals with a

31.7-dB/$^{\circ}$K G/T ($\leq$40 ft antenna diameter), a capacity of 400 telephone circuits may be achieved. Alternately, a television signal plus about 100 telephone circuits may be accommodated per transponder. Television transmissions use FM. Telephony and telegraphy typically use digital SCPC. Preassigned links are used in some countries and demand assigned links or a mix of both are used in other countries.

Most terminals in use have a performance near 31.7 dB/$^{\circ}$K G/T, which is the Intelsat standard B (Table 4-11). Some terminals with smaller antennas are being used. The choice is left to the leasing country to arrive at a balance of cost and satellite capacity in choosing ground terminal performance. The number of ground terminals in a country varies from two to more than 100.

Originally, Intelsat provided the leased transponders from excess capacity on its spare satellites. This is still true, but in addition some older satellites not needed as spares have been devoted to leased service. The satellites currently used for leased services are identified in Tables 4-4, 4-5, and 4-7. Because of the rapid growth of this service, Intelsat has now included it in its traffic forecasts to ensure that adequate satellite capacity will continue to be available. In addition, Intelsat has studied the possibility of developing satellites optimized for leased services.

Table 7-42. Intelsat Leases

In Use (early 1983)	Planned Use (start 1983-1985)
Algeria	Angola
Argentina	Bangladesh
Australia	Bolivia
Brazil	Cameroon
Chile	China (P.R.C.)
Colombia	Ecuador
Egypt	Mali
France	Mauritania
Greenland	Pakistan
India	South Africa
Libya	Sri Lanka
Mexico	Thailand
Morocco	United Kingdom
Niger	Venezuela
Nigeria	West Germany
Norway	
Oman	
Peru	**Past Uses**
Portugal	
Saudi Arabia	Malaysia[a]
Spain	Uganda
Sudan	United States[b]
Zaire	

[a]Now leasing from Indonesia (Palapa satellites).
[b]CONUS to Hawaii traffic now on U.S. domestic communication satellites.

7.20 OTHER SYSTEMS (Refs. 748-752)

7.20.1 The Philippines

By 1974 the Philippines had developed a plan to use satellites to improve its national communications facilities. Satellites are preferrable to terrestrial links because of the rugged and scattered island geography and because terrestrial links are more easily damaged by the frequent typhoons and earthquakes that occur there.

The Philippines applied for an Intelsat lease and were accepted. The start of operations was planned for 1976; however, it eventually was canceled. Instead, the Philippines began using leased capacity on the Indonesian Palapa satellites. The capacity is used for distribution of television to remote areas and for an alternative to terrestrial facilities for telephone links.

7.20.2 Malaysia

Malaysia uses satellites for communications between its mainland and islands. Operations began in 1975 with a leased Intelsat transponder. In 1980 the lease was completed and traffic transferred to the Palapa satellites under a lease agreement with Indonesia.

7.20.3 Planned Systems

Columbia is using leased Intelsat capacity for communications between the capital, a Caribbean island, and a city in the undeveloped interior. In the spring of 1982 proposals were submitted to Columbia for development of 24 transponder 4- and 6-GHz satellites. However, in the fall of 1982 a new government indefinitely postponed the acquisition of dedicated satellites pending further study of the country's needs.

China began using the Intelsat system for international communications almost ten years ago. Beginning in 1978 there were reports that China was developing its own communication satellite. Also, from 1978 to 1980 the Chinese made several visits to the U.S. and Western Europe to discuss the purchase of communications and broadcasting satellites. However, in 1981 and 1982 China announced that these plans would be postponed for many years because of the country's economic situation. During this same period China had conducted experiments with one of the Symphonie satellites which had been positioned over the Indian Ocean. The next specific step was an Intelsat lease, use of which began in 1983. In April 1984 China launched STW-1 (Shiyan Tongxin Weixing - experimental communications satellite). It is reported to be about 7 ft in diameter, 10 ft high including the antenna, weigh 900 lb, and use the 4- and 6-GHz bands. Future plans include an operational communication satellite based on STW-1.

Both Luxemburg and Cuba have announced definite plans for satellites. Luxemburg intends to launch both a television broadcast satellite and a communication satellite. Cuba plans a communication satellite. All are to be launched by the end of the 1980s, but no hardware development has been initiated.

8. OTHER SATELLITES

In this section, several satellites are discussed that do not fall into the previous categories. Some of these systems do not compare to the other programs in terms of expenditure or communication capacity, but they illustrate the variety of applications found for satellite communications. Of particular note are the Oscar satellites developed by amateur radio operators, mostly with donated time and materials. Although the Oscars are physically small, they are the product of international cooperation, and they have been used by over 10,000 people in more than 100 countries. Another class of satellites described in this section is meteorological types which also include transponders for relaying data from many unattended data collection platforms to a central site. A third class is satellites whose payload consists of one or more beacon transmitters. These satellites can be used by a system operator to gain experience in satellite development and/or operations, to check ground control networks, or as sources for propagation studies.

8.1 SATELLITES FOR RADIO AMATEURS

8.1.1 Oscar (Ref. 753-770)

Oscar (Orbiting Satellite Carrying Amateur Radio) is a space project of amateur radio operators. The Oscar project was started in 1960 by amateurs in California, most of whom were professionally involved in space technology activities. The Oscar satellites are launched as secondary payloads occupying excess, and otherwise unused, launch vehicle capability. Six communication satellites have been launched (Table 8-1). Four other amateur satellites have also been orbited. The first two satellites, Oscar 1 and 2, were launched in December 1961 and June 1962. These satellites transmitted beacon signals with simple modulation. Each weighed about 10 lb and operated about 400 hr.

Oscar 3 was the first amateur communication satellite. The satellite repeater had a 50-kHz bandwidth operating in the 144- to 146-MHz band. This satellite operated more than two weeks until the battery was depleted. A number of two-way links were established by radio operators in the U.S., Canada, and Europe. One-way transatlantic links were established twice. Oscar 4 also had a communications repeater with a 10-kHz bandwidth. However, because of a launch vehicle failure, the desired orbit was not achieved, and only a few two-way contacts were established. However, one of these was the first direct satellite link between the U.S. and U.S.S.R. These four satellites form the first phase of amateur satellite work.

In 1969 the Radio Amateur Satellite Corporation (Amsat) was formed to continue the Oscar project and expand it to international participation. Oscar 5 was a beacon satellite prepared by amateurs in Australia. It was the first Oscar to have a command subsystem, an important step toward long life, complex satellites. This satellite and Oscars 6, 7, and 8 were the second phase of amateur satellites, characterized by multiyear lives in low orbits.

Oscars 6 through 8 all had command subsystems and were powered by solar arrays coupled with rechargeable NiCd batteries. They used magnets to

provide two-axis stabilization, aligning the spacecraft axis with the local geomagnetic field. Portions of these satellites were built in the U.S, Australia, West Germany, Canada, and Japan. They were assembled in the U.S. While almost all the labor was done by amateurs, many hardware items were donated by government and industrial organizations. The design lives of these three satellites were one, three and three years, but each operated about five years. Oscars 7 and 8 are illustrated in Figure 8-1.

Oscar 6 had a communication repeater with a 100-kHz bandwidth; it received at 146 MHz and transmitted at 29.5 MHz (Figure 8-2). Oscar 7 had two repeaters. One was the same as Oscar 6 except for a slight frequency change and increased output power. The other received at 432 MHz and transmitted at 146 MHz. An onboard timer automatically switched from one repeater to the other every 24 hours. This timer was part of the control circuitry that automatically switched one repeater on in a low power mode when the battery was discharged to a certain point. On several occasions these two satellites were used together with a 432-MHz uplink to Oscar 7, a 146-MHz intersatellite link, and a 29-MHz downlink from Oscar 6. Oscar 8 also had two repeaters. One was the same as Oscar 7, operating at 146/29 MHz. The other received at 146 MHz and transmitted at 435 MHz. Only one repeater was on at a time.

The next amateur satellite in orbit was UOSat, launched in October 1981. Its name comes from the University of Surrey, England, where it was constructed. Its purpose is to broaden amateur interest in space and provide for new educational experiments through a variety of equipment. It has a magnetometer, two particle counters, a speech synthesizer, an earth imaging sensor, and several propagation beacons. A second UOSat was launched in March 1984.

Oscars 9 and 10 are the beginning of the third phase of amateur communication satellites, characterized by long life and high altitude orbits. The satellite (Figure 8-3) is shaped like a three-pointed star. The satellite is spin-stabilized and has magnetic torquers to control the spin orientation. The spin axis is oriented so that, at apogee, the antennas point

toward the center of the e... A microprocessor monitors telemetry and has a considerable autonomous contro capability. All electronics are mounted in the arms of the satellite. A motor located in the center of the satellite is used to raise its orbital apogee and inclination. The goal of the chosen orbit is to provide long duration coverage to the largest possible number of amateur radio operators. The satellite has two repeaters. One uses the 435/146-MHz combination used before. The other is the first amateur use of a higher uplink frequency (1269 MHz), coupled with a 435-MHz downlink.

The West German Amsat organization has the central role in Oscar 9 and 10. It received support and equipment from several European countries and the U.S. Oscar 9 was destroyed by a launch vehicle malfunction in 1980. Oscar 10 was launched in June 1983. It encountered some difficulties which resulted in a less than optimum orbit. Use of the satellite for communications began in August 1983.

8.1.2 RS (Refs. 770-772)

RS is the designation for amateur radio communication satellites developed in the U.S.S.R. The RS satellites are similar to Oscar 6, receiving at about 146 MHz and transmitting in the 29-MHz band with a few watts output and a bandwidth of 100 kHz.

The original RS announcement was made in 1977. At the end of October 1978, two satellites were launched into a near-polar orbit with an altitude of about 900 nmi. After launch the U.S.S.R. referred to these satellites as Radio 1 and 2. A set of six satellites, named Radio 3-8, were launched together in December 1978. Their orbit is similar to that used for the first two satellites.

Three Iskara* (or Iskra) satellites have also been announced to be for amateur radio communications. No description has been given. The first

*Spark.

was launched in July 1981. The others were deployed from the Salyut 7 space station in May and November 1982. Because of their low orbits, each decayed within two months.

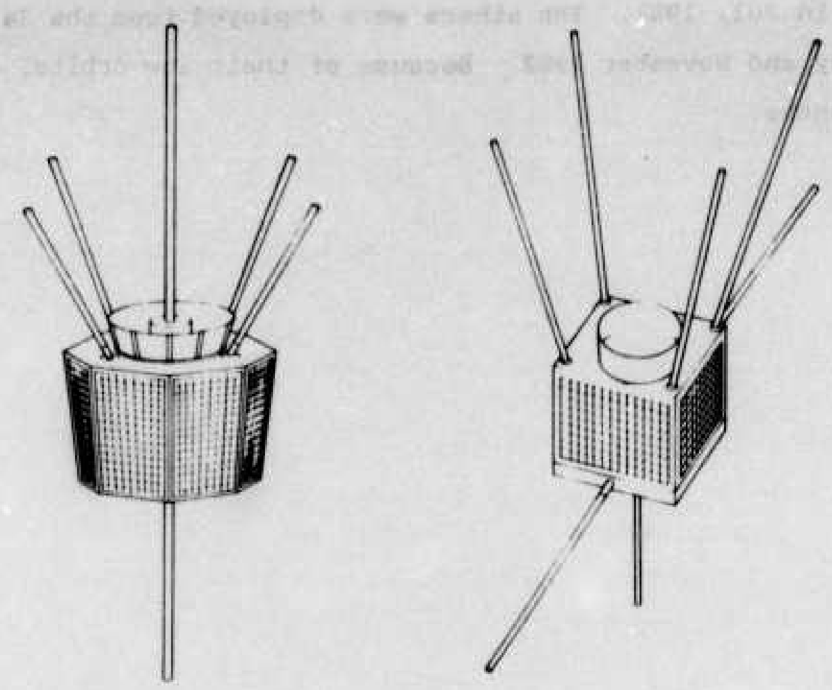


Figure 8-1. Oscar 7 and 8 Satellites

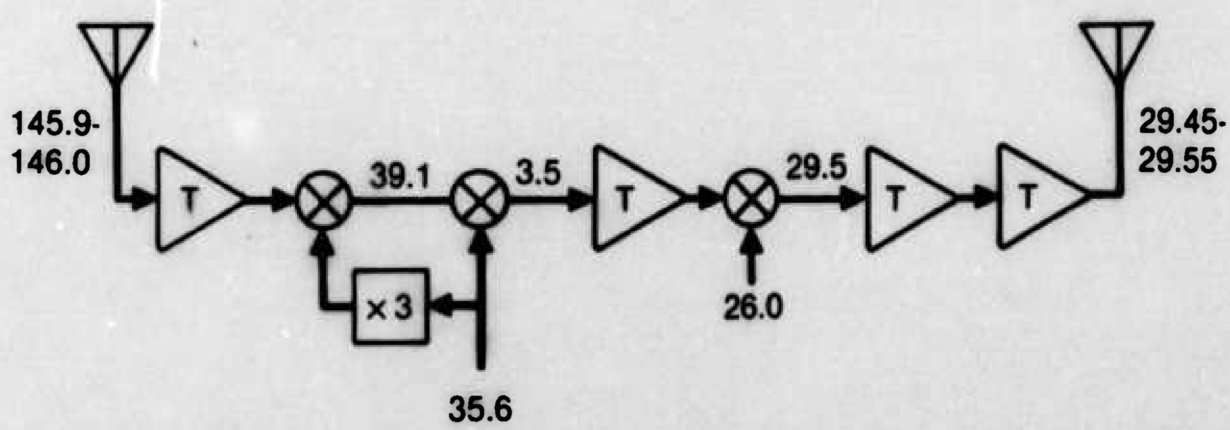


Figure 8-2. Oscar 6 to 8 146/29-MHz Communication Subsystem

Table 8-1. Oscar Details

Parameter	Oscar 3	Oscar 4	Oscar 6	Oscar 7	Oscar 8	Oscar 10
Shape	Rectangular	Tetrahedron	Rectangular	8-sided cylinder	Cube	3-arm "star"
Size	7 x 12 x 17 in.	19-in. sides	6.4 x 12 x 17.3 in.	17-in. diameter, 17-in. high	18-in. sides	17 in. tall 50 in. span
Orbital Weight, lb	33	29	40	65	60	~200
Solar Array Max. Output, W	2.5	10	5.5	15	15	50
Bandwidth, kHz	50	10	100	100 50	100 100	150 800
Transmit Frequency,[a] MHz	145.9	431.9	29.5	29.45 145.95	29.45 435.15	145.895 435.55
Transmitter Power, W	1	3	1 to 1.3	2 2 or 10 (average) 4 or 14 (peak)	1 to 2 1 to 2	50 (peak)
Receive Frequency,[a] MHz	144.1	144.1	145.95	145.9 432.15	145.9 145.95	435.225 1269.55
Antenna	Monopoles	Monopoles	Dipole (29 MHz) Monopole (146 MHz)	Dipole (29 MHz) Turnstile (146 MHz)	Dipole (29 MHz) Turnstile (146 MHz) Monopole (435 MHz)	3 Monopoles (143 MHz) 3 Dipoles (435 MHz) Helix (1269 MHz)
Design Life	4 mo	1 yr	1 yr	3 yr	3 yr	
Orbit, nmi	490 x 510	100 x 18,300	785 x 785	783 x 786	490 x 495	2134 x 19,175
Inclination	70°	26°	102°	102°	99°	26°
Launch Date	9 Mar 1965	21 Dec 1965	15 Oct 1972	15 Nov 1974	5 Mar 1978	16 Jun 1983
Operated Until	24 Mar 1965	Mar 1966	Turned off in Jun 1977	Operated until mid 1981	Operated about 5 yr	In Use

[a]Center frequencies of transmit and receive bands.

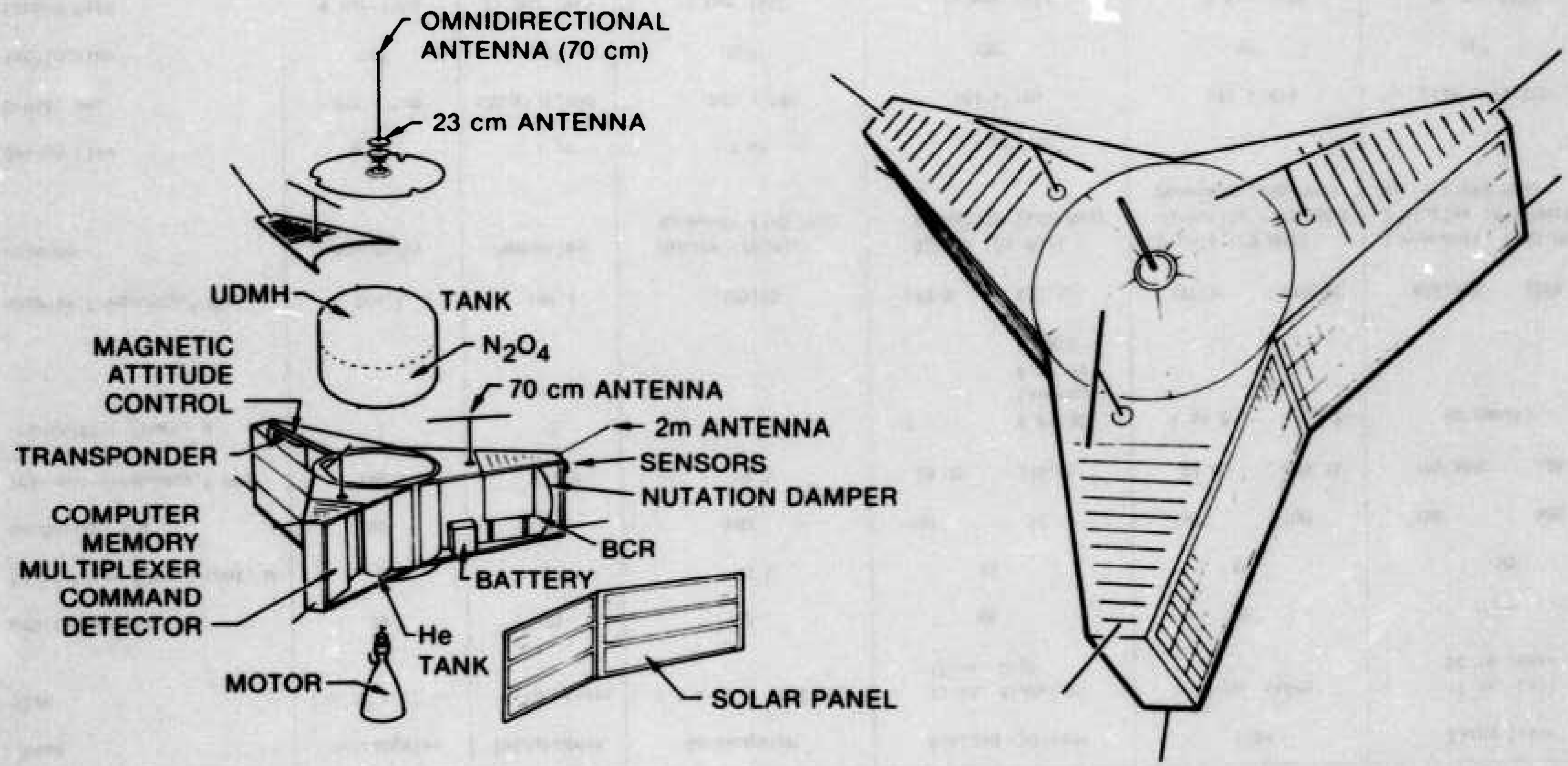


Figure 8-3. Oscar 10 Satellite

8.2 LES-3 (Refs. 41, 42)

The third Lincoln Experimental Satellite (LES-3) payload was a beacon whose output was used for propagation measurements. The phenomenon of most interest was multipath. The beacon frequency was 232.9 MHz, which is in the range of frequencies (approximately 230 to 280 MHz) used by many military communication satellites that followed LES-3. The beacon was modulated by a 15-bit sequence from a four-stage pseudorandom source. The modulation rate was 100 kbps. The modulated signal was amplified and equally split to two monopole antennas.

The LES-3 satellite (Figure 8-4) is similar to LES-1 and -2 except for the payload. The body has 18 square and eight triangular faces. The antennas are mounted to the center of two opposite square faces. Solar cells are mounted on the square faces. The satellite had no battery, and no command and telemetry. The beacon was activated automatically at orbital insertion. Other details about the satellite are given in Table 8-2.

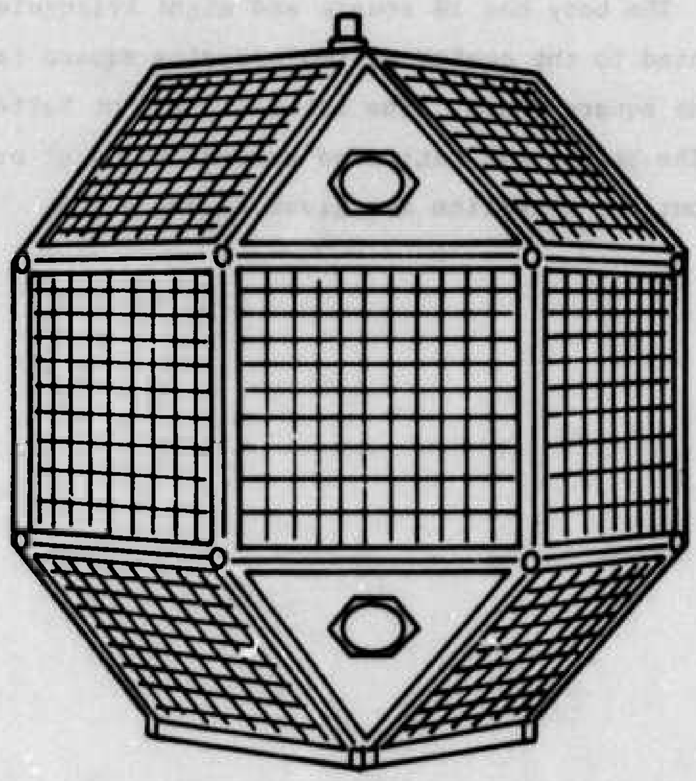


Figure 8-4. LES-3 Satellite

Table 8-2. LES-3 Details

Satellite	26-sided polyhedron, 2-ft diameter, 4 ft between ends of antennas 34 lb in orbit Solar cells, no batteries, 25 W maximum at beginning of life Spin-stabilized, ~140 rpm
Configuration	One beacon transmitter
Transmitter	232.9 MHz, 100 kHz biphase modulation, 10 W power output, 15 dBW maximum ERP
Antenna	Two quarter-wave monopoles, extending from opposite faces of the satellite body, toroidal pattern
Design Life	1 yr
Orbit	Subsynchronous equatorial, ~18,200 nmi altitude intended; 105 x 18,200 nmi, 26° inclination actual
Orbital History	Launched 21 Dec 1965 Operated more than one year Decayed 6 Apr 1968 Titan III-C launch vehicle (shared with other satellites)
Developed by	MIT Lincoln Laboratory

8.3 OV4 (Refs. 773-774)

The OV4 experiment is of historical interest as it was the first satellite-to-satellite crosslink. Beginning in 1948, communication between near-antipodal points on the earth had been demonstrated at frequencies well above what was expected based on traditional understanding of HF propagation. Then, when the space age began, there were many reports of ground-based reception of HF or VHF transmissions from satellites far beyond the horizon. Various modes of ionospheric propagation were suggested to explain these phenomena.

The OV4 experiment was developed to extend the investigations of ionospheric propagation. A secondary purpose was to determine the feasibility of communication beyond the line of sight between two low altitude satellites. A number of Air Force experimental satellites that were flown in the 1960s were designated OVs, or orbiting vehicles. OV4 was the fourth basic type of OV. The OV4-1T and OV4-1R were separate satellites, which were the transmitting and receiving portions, respectively, of the link. The OV4-1R also had a telemetry transmitter.

The two satellites were launched together into the same orbit, and were then given a slight relative velocity so that their separation varied from zero to antipodal. These satellites were launched in early November 1966 and operated until the end of that year. OV4-1T operated continuously, but the OV4-1R operated only by command when it was in sight of a ground terminal equipped to receive and record the experiment telemetry. About 30 telemetry records were gathered, indicating successful operation at ranges varying from a few hundred miles to antipodal distance. Other experiment details are given in Table 8-3.

Table 8-3. OV4 Details

Satellite	OV4-1T: Cylinder with 1 domed end, 17-in. diameter, 45 in. long
	OV4-1R: Cylinder with 1 domed end, 17-in. diameter, 37 in. long
	240 lb (T), 300 lb (R)
	Silver oxide-zinc batteries, 7.9 kWh
	No stabiliziation
Transmitter	20.75, 34.3, and 46.8 MHz
	20-, 100-, and 1000- μsec pulse widths
	2-, 100-, and 1000-W peak power levels
Receiver	20.75, 34.3, and 46.8 MHz
Antenna	Dipole with linear polarization on each satellite
Orbit	150- to 160-nmi altitude, 33° inclination
Orbital History	Launched 3 Nov 1966
	Operated until 30 Dec 1966
	Decayed in Jan 1967
Developed for	U.S. Air Force
Developed by	Raytheon

8.4 TEST AND TRAINING SATELLITES (Refs. 775-776)

The Test and Training Satellites (TETR or TTS) were developed by NASA for use during exercises of the Manned Spaceflight Network. The primary purpose of a TTS was to simulate the downlink of an Apollo spacecraft for network checkout prior to an Apollo flight. The TTS performed the simulation by retransmitting a sample downlink signal that it had received from a ground station. This signal could include ranging, telemetry, voice, and biomedical data. Four of these satellites were launched as secondary payloads. Details of the TTS satellites are given in Table 8-4.

Table 8-4. TTS Details

Satellite	Octahedron, 12 in. on a side		
	40 to 45 lb in orbit		
	Solar cells and battery, 4 to 5 W		
Transmitter	2282.5 MHz		
	0.8-W output		
Receiver	2101.8 MHz		
Design Life	7 months		
Orbital History	Satellite	Launch Date	Orbit
	1	13 Dec 1967	158 x 261 nmi, 33° inclination
	2	8 Nov 1968	202 x 510 nmi, 33° inclination
	3	27 Aug 1969	Launch vehicle failure
	4	29 Sep 1971	215 x 329 nmi, 33° inclination
Developed for	NASA		
Developed by	TRW		

8.5 EOLE (Refs. 777-779)

Eole was a satellite developed by the French national space agency for communication with and data collection from remote balloon-borne meteorological sensors. It was a cooperative program with NASA called CAS-A. Peole (Preparation for Eole) was an experimental satellite with a similar payload. The basic function of Eole was to interrogate the sensors and to relay data from them to a ground station. During the first five months after Eole was launched, 500 weather balloons were released from Argentina. Eole relayed pressure and temperature data from them to a station in France. Eole was also used to determine the location of the balloons to provide data on wind velocity.

Eole (Figure 8-5) was gravity gradient stabilized with antennas on the end that was oriented toward the earth. Solar cells were mounted on both the satellite body and the panels, which were deployed in orbit. Eole had two communication subsystems: one operated at 401 and 464 MHz for links with sensor platforms and the other used 136 and 148 MHz for links with ground terminals. The satellite had an onboard memory so that it could collect sensor data even when it was not in sight of a ground terminal. The links between Eole and the sensor platforms were designed so that the satellite could collect data on the link range and range rate. On the ground, this information was used to compute the sensor platform location. Satellite details are given in Table 8-5.

Eole was launched in August 1971 by a NASA Scout Vehicle. Although the design life was six months, it operated over two years. Following the initial balloon experiments, Eole was used to relay data from a variety of other sensor platforms.

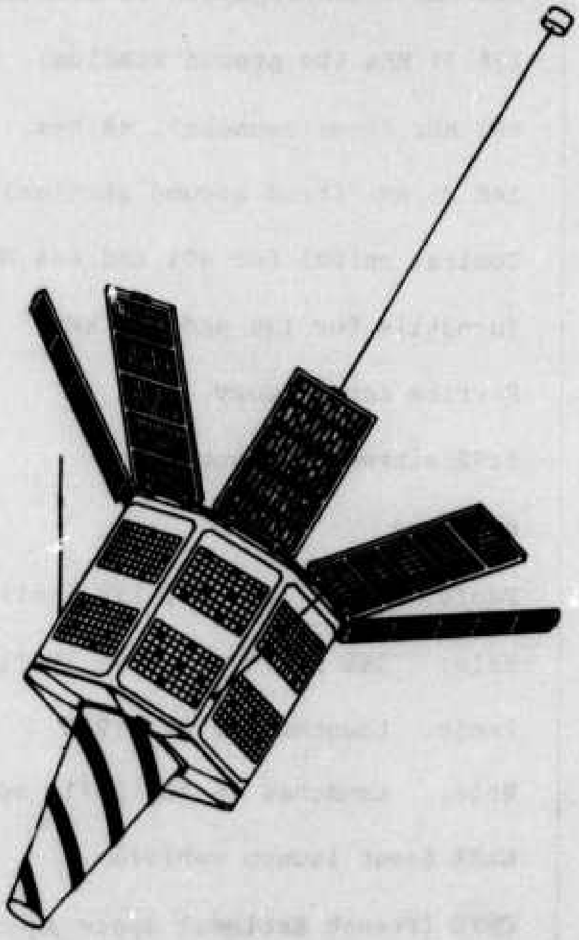


Figure 8-5. Eole Satellite

Table 8-5. Eole Details

Satellite	Octagonal cylinder, 28-in. diameter, 21.5 in. high, overall height ~46 in. (excluding gravity gradient boom)
	186 lb in orbit
	Solar cells
	Gravity gradient stabilization
Transmitter	464 MHz (interrogation of sensors), 4-W output, 48 bps
	136.35 MHz (to ground station), 250-mW output, 1536 bps
Receiver	401 MHz (from sensors), 48 bps
	148.25 MHz (from ground station)
Antenna	Conical spiral for 401 and 464 MHz
	Turnstile for 136 and 148 MHz
Onboard Storage	Ferrite core memory
	8192 sixteen-bit words
Design Life	6 months
Orbit	Peole: 270 x 386 nmi, 15° inclination
	Eole: 365 x 478 nmi, 50° inclination
Orbital History	Peole: Launched 12 Dec 1970
	Eole: Launched 16 Aug 1971, operated more than 2 yr
	NASA Scout launch vehicle
Developed for	CNES (French National Space Agency)
Developed by	Laboratoire Central de Télécommunications (France)

8.6 GOES (Refs. 780-782)

The Geostationary Operational Environmental Satellites' (GOES) primary mission is to gather and disseminate data concerning the earth's surface and atmosphere. To accomplish this mission, the satellites are equipped to perform three functions. The first is making visible and infrared measurements of the surface and atmosphere and transmitting these data to a command and data acquisition station (CDAS) at Wallops Island, Virgina. The measurements are made by the Visible infrared spin scan radiometer Atmospheric Sounder (VAS). The VAS operates at multiple wavelengths; its best resolution is 0.9 km in visible light and 6.9 km in infrared. The second function of the satellites is to relay processed VAS data and other weather data from the CDAS to receivers at various user locations. The third function is to provide two-way communications between the CDAS and many unattended data collection platforms. The Japanese Geostationary Meteorological Satellites (GMS) are to have the same function and design. The ESA Meteosats are similar.

Two Synchronous Meteorological Satellites were predecessors to the GOES. They, and GOES 1 to 3 were of the same design. Beginning with GOES 4 the radiometer was improved to become the VAS, and the satellite design changed. The GOES 4 version of the satellite is shown in Figure 8-6. The cylindrical body, VAS, and VAS sunshade are joined and spin to provide stabilization. The spinning also provides the east-west scanning motion for the VAS; north-south scanning is accomplished by tilting an internal mirror. The antenna assembly is despun and continuously points toward the earth. All communications and support equipment is mounted inside the body. A rotary joint connects the antennas to the communications electronics. The magnetometer, X-ray sensor and EPS sensors shown in the figure are for monitoring the space environment.

The GOES communication subsystem is shown in Figure 8-7. The 28 Mbps VAS data are brought into the S-band receivers and QPSK modulate an 84-MHz carrier. This carrier is upconverted, then amplified in the S-band driver and transmitter stages for transmission to the ground. The VAS views the earth,

and outputs data, for only 37.5 milliseconds of every 600 millisecond spin period. During the remaining time the modulator is disconnected, and signals received through the S-band antenna are retransmitted at S-band. These signals include processed VAS data at 1.7 Mbps and weather facsimile data at lower rates. Every thirty minutes enough processed data is transmitted to produce a global picture of cloud patterns and temperature profiles. This S-band channel is also used for low duty cycle transmissions of ranging signals between three widely separated stations.

The CDAS may interrogate data collection platforms (DCP) via a link transmitted to GOES at S-band. An intermediate frequency signal from the S-band receivers is routed to the UHF receivers and retransmitted to the platforms at UHF. Return UHF signals from the platforms are received and routed to the DCP transmitter which operates at S-band. The DCPs monitor pressure, temperature, rain, snow, river levels, ocean currents, etc. Their transmissions, at 100 bps, are initiated by interrogation from the CDAS, an internal timer, or occurance of a specific phenomenon. The GOES return channel can accommodate up to 188 simultaneous transmissions on separate frequencies.

Table 8-6 provides additional data on the GOES satellites. The system uses two operating satellites, which are currently numbers 5 and 6. Satellites 2 through 4, which are in various states of health, provide a back-up capability. The two operating locations, 75^{o} and 135^{o}W longitude, together provide good coverage of the U.S. and offshore areas.

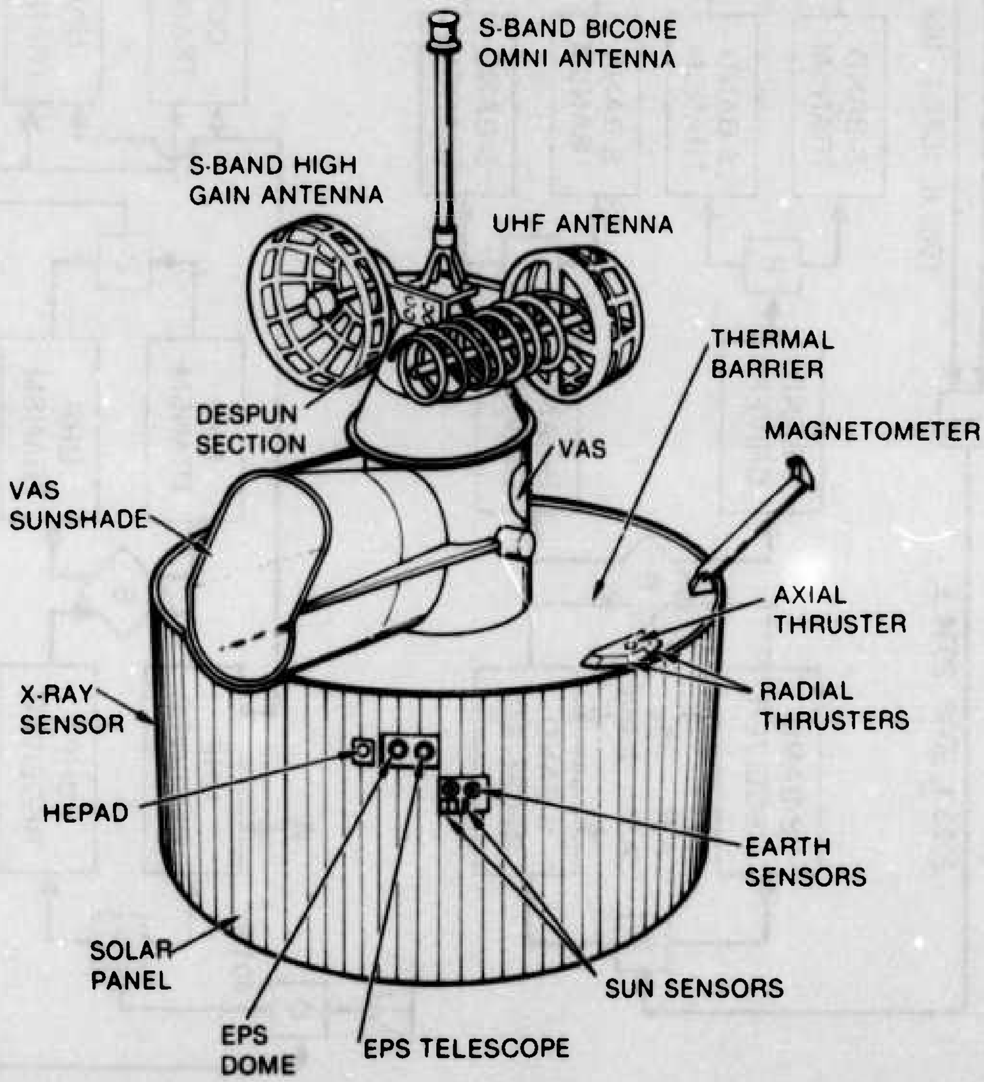


Figure 8-6. GOES Satellite

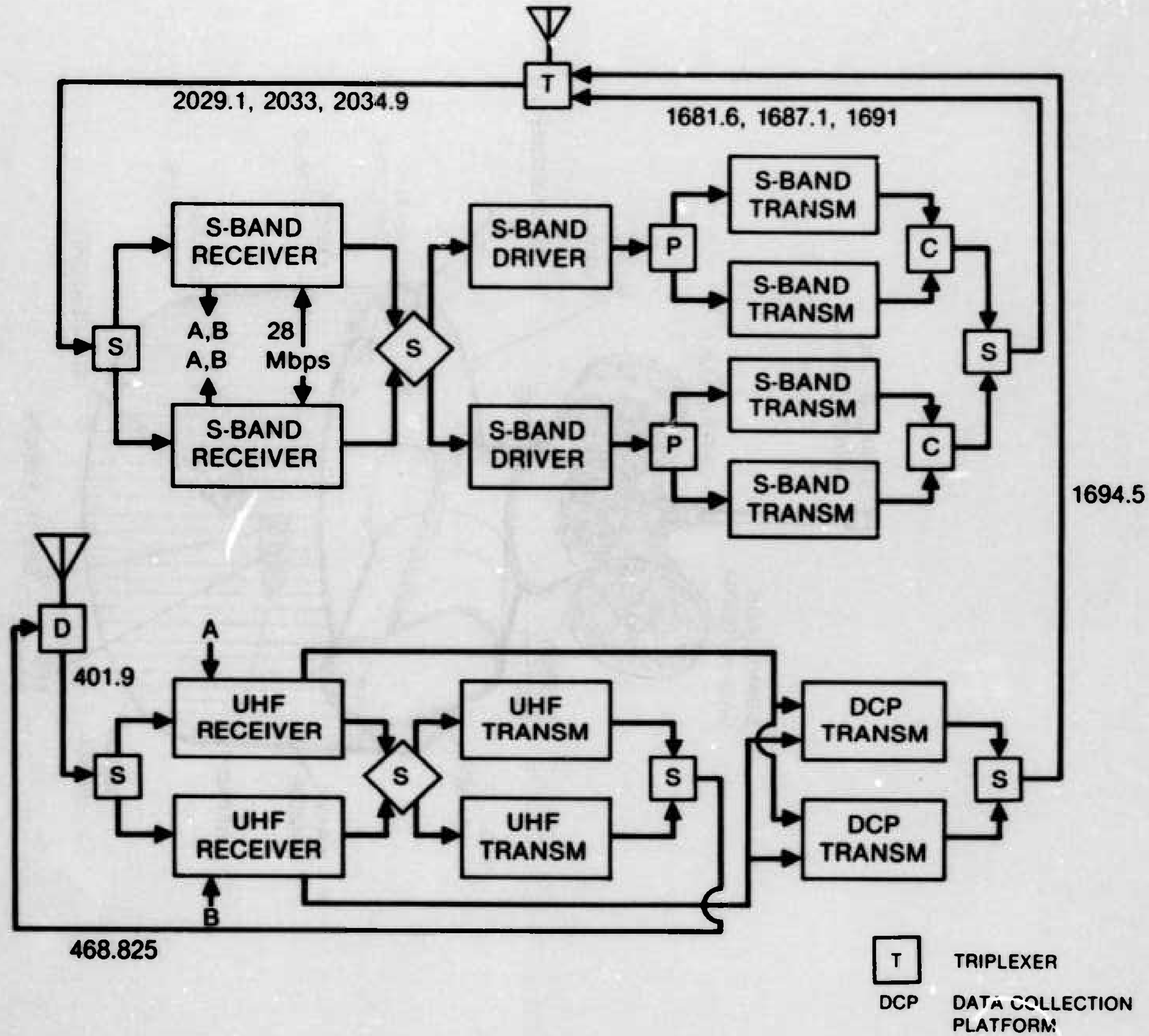


Figure 8-7. GOES Communication Subsystem

Table 8-6. GOES Details

Satellite	Cylinder, 85[a]-in. diameter, ~40[a] in. high, height including antennas 143 in. 975[a] lb in orbit Solar cells and NiCd batteries, 320[a] W after 7 yr Spin-stabilized, 100 rpm, ±0.1° pointing accuracy
Configuration	A: Transmission of 28 Mbps data generated onboard, time-shared with retransmission of received data (all S-band) B: One transponder for transmissions from a central station to remote platforms (S-band to UHF) C: One 200-kHz bandwidth transponder for up to 188 FDMA, 100 bps transmissions from remote platforms to a central station (UHF to S-band)
Transmitter	A: 1681.6 MHz for internal data, 1687.1 and 1691 MHz for retransmitted data 20 W output, ~26 dBW ERP at edge of earth B: 468.825 MHz 4 W output, ~16 dBW ERP at edge of earth C: 1694.5 MHz 0.5 W output, 6.5 dBW ERP at edge of earth
Receiver	A: 2029.1 and 2033 MHz -17.6 dB/°K G/T at edge of earth B: 2034.9 MHz -17.6 dB/°K G/T at edge of earth C: 401.9 MHz -18.5 dB/°K G/T at edge of earth

Table 8-6. GOES Details (Continued)

Antenna	One vertically polarized S-band parabolic antenna and one RHCP UHF helix, each has an earth coverage beamwidth
Design Life	7[a] yr
Orbit	Synchronous equatorial
Orbital History	SMS[b] 1: Launched 17 May 1974, moved to higher altitude after useful life
	SMS[b] 2: Launched 6 Feb 1975, moved to higher altitude after useful life
	GOES 1: Launched 16 Oct 1975, moved to higher altitude after useful life
	GOES 2: Launched 16 Jun 1977, spare?, 41°W longitude
	GOES 3: Launched 16 Jun 1978, spare?, 91°W longitude
	GOES 4: Launched 9 Sep 1980, spare, 143°W longitude
	GOES 5: Launched 22 May 1981, active, 75°W longitude
	GOES 6: Launched 28 Apr 1983, active, 135°W longitude
	GOES 7 and 8: Launch scheduled in 1986
	Delta 2914 launch vehicle (through GOES 3)
	Delta 3914 launch vehicle (beginning with GOES 4)
Developed for	NASA, acting for National Oceanic and Atmospheric Administration (NOAA)
Developed by	Ford Aerospace (through GOES 3)
	Hughes Aircraft Company (beginning with GOES 4)
Operated by	NOAA

[a]Applies to GOES 4 and succeeding satellites.
[b]See text.

8.7 Satellite P76-5 (Ref. 783)

Satellite P76-5 was one of many scientific satellites launched by the Air Force Space Test Program. Its payload was a multifrequency radio beacon called the DNA (Defense Nuclear Agency) Wideband experiment. The experimental program using this beacon was designed to characterize the perturbations imposed on radio waves as they propage through structured plasmas in the ionosphere. The program included measurements of amplitude fading and phase scintillations as functions of time, frequency, and location.

The Wideband experiment transmitted ten phase coherent signals all derived from a single crystal oscillator. The ten frequencies included one VHF, seven UHF, one L-band and one S-band. Specific frequencies are listed in Table 8-7. The S-band signal served as an undisturbed (at most times) phase reference for the lower frequencies. All were transmitted with circular polarization.

The P76-5 satellite was a modified Transit satellite from the Navy navigation satellite program. The modification was primarily substituting the Wideband experiment for the navigation payload. The satellite body was an octagonal cylinder. A gravity gradient boom was deployed from the satellite in the antiearth direction, and four solar panels unfolded into the plane normal to the boom, spaced 90 deg apart. The experiments' antenna was on the earth-facing side of the satellite. Table 8-7 gives additional information.

Table 8-7. P76-5 Satellite Details

Satellite	Octagonal cylinder 12 in. high, 18-in. diameter; height with gravity gradient boom ~100 ft; span across opposite solar panels ~10 ft ~110 lb in orbit Solar array and NiCd batteries, 45 W beginning of life Gravity gradient stabilization
Transmitter	137.675 MHz Harmonic[a] 12, 26 dBW ERP 378.606 33, 27 390.079 34, 26 401.552 35, 30 413.024 36, 27 424.497 37, 27 435.970 38, 25 447.443 39, 28 1239.073 108, 25 2891.171 252, 27
Antenna	Several radiators with a 60-in. ground plane, approximately earth coverage beams with lower gain at beam center to approximate uniform coverage, RHCP
Orbit	532 x 567 nmi, 99.6° inclination, sun synchronous
Orbital History	Launched 22 May 1976 Scout launch vehicle
Developed for	Defense Nuclear Agency
Developed by	RCA (satellite), Stanford Research Institute (experiment)

[a]Of 11.4729 MHz.

8.8 ENGINEERING TEST SATELLITE, TYPE II (Refs. 655, 657, 784)

The Japanese Engineering Test Satellite, Type II (ETS II or Kiku II) was a beacon satellite whose purposes were to develop and test Japan's ability to launch and control a synchronous orbit satellite and to make propagation measurements. The ETS II (Figure 8-8) was a U.S.-built satellite with a design that was basically the same as Skynet I. It was a spin-stabilized satellite with a set of three antennas that were despun. Each antenna was used for one of the beacon transmissions, which were at 1.7, 11.5, and 34.5 GHz. All three frequencies were derived by multiplication from a common oscillator at about 213 MHz. Additional design details are given in Table 8-8. The propagation measurements in the ETS II program were signal level and cross-polarized level at each frequency and phase differences between several pairs of signals and cross-polarized components.

ETS II was launched from Tanegashima, Japan in February 1977. The launch vehicle was a Japanese N rocket, built under license and based on the 1970-style Delta launch vehicle. This launch served as a test of the N rocket and control network for the ECS launch in 1979 (Section 7.12.3). Initial tests were conducted in March 1977, and the propagation experiment was operated from April 1977 to May 1978.

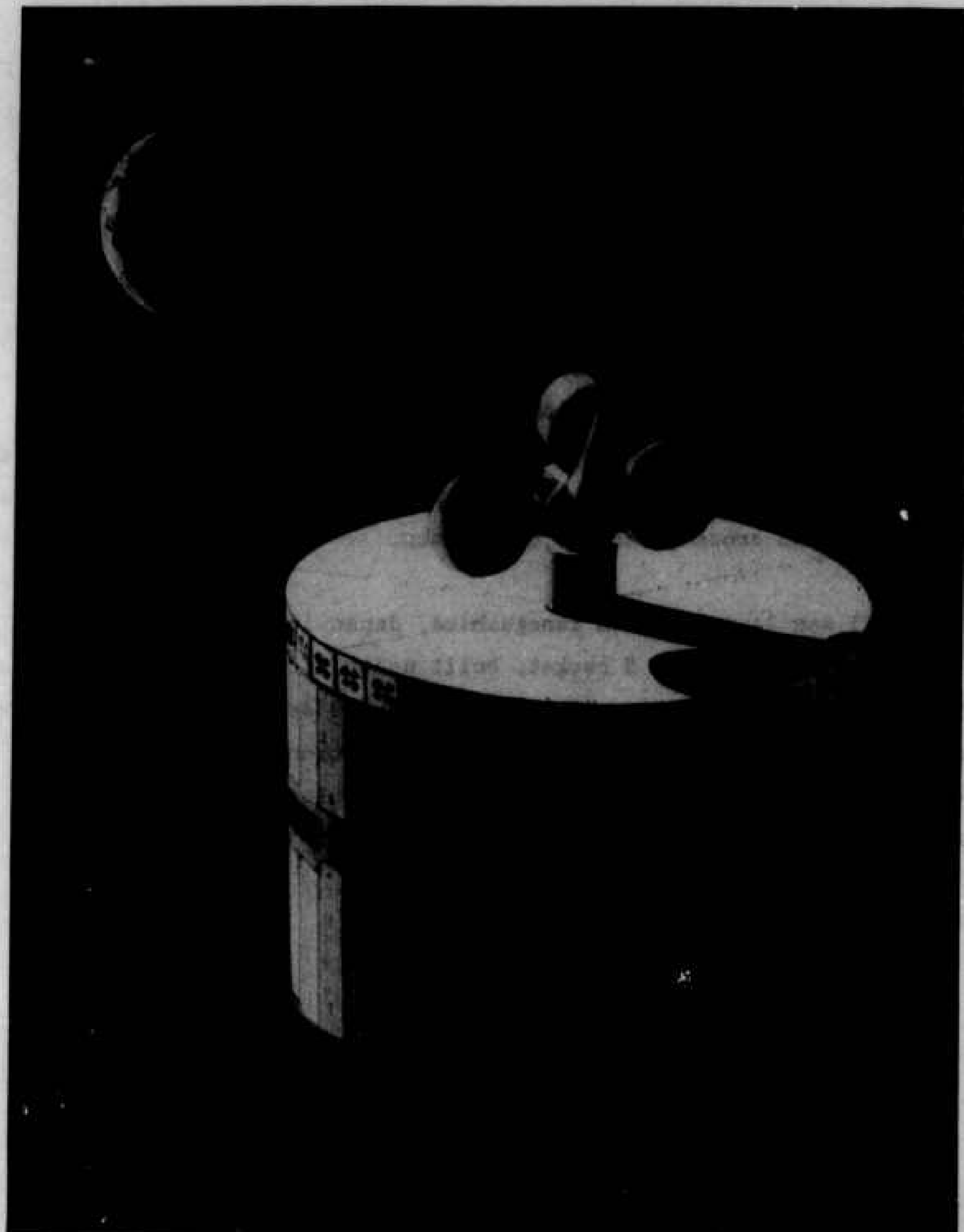


Figure 8-8. ETS II Satellite

Table 8-8. ETS II Details

Satellite	Cylindrical body, 55-in. diameter, overall height 71.5 in. 286 lb in orbit Solar cells and NiCd batteries, 92 W minimum after 1 yr Spin-stabilized, ~100 rpm, $\pm 0.5^{o}$ antenna pointing accuracy
Configuration	Three beacon transmitters
Transmitter	1.705 GHz: CW or 100% amplitude modulation by 300-Hz square wave, 6-dBW measured ERP 11.50875 GHz: CW, 20-dBW measured ERP 34.52625 GHz: CW or 100% amplitude modulation by 300-Hz square wave, 24-dBW measured ERP
Antenna	2 parabolic reflectors - one each for 11.5 and 34.5 GHz, 2.2^{o} beamwidth at 34.5 GHz 1 end-fire antenna in a cavity for 1.7 GHz
Design Life	1 yr
Orbit	Synchronous equatorial, 130^{o}E longitude, E-W stationkeeping to $\pm 0.5^{o}$
Orbital History	Launched 23 Feb 1977 Operations ended May 1978 N launch vehicle
Developed for	National Space Development Agency of Japan
Developed by	Ford Aerospace and Communications Corporation under contract to Mitsubishi
Operated by	NASDA

8.9 SARSAT (Ref. 785-787)

Many aircraft and ships carry small transmitters which may be used to broadcast an emergency signals. However, due to their limited power, they have a short range. Thus, in most cases, rescue organizations must be alerted to the emergency by other means and home on the transmitted signal only after they reach the vicinity of the emergency. Since satellites can see a large portion of the earth, they have a much better chance of receiving these emergency signals. Satellite reception is now being tested in a program called Sarsat (search and rescue satellite-aided tracking). This program is a cooperative effort of the U.S., Canada, France, and the U.S.S.R.

The emergency transmitters which were developed in the past decade transmit a distinctively modulated signal. The transmission is continuous from activation as long as power is available. Civilian transmitters use 121.5 MHz and military transmitters use 243 MHz. Units now being developed transmit in the 406- to 406.1-MHz band. They have improved frequency stability which simplifies the processing required to extract position information from the received, Doppler shifted frequency. In addition, they transmit only a 440-msec burst approximately every 50 seconds. This is so that multiple transmitters within view of one satellite will have a small probability of interfering with each other. Finally, their burst transmissions contain data which will include the identity of the vessel in trouble and perhaps also its estimated location.

In the current Sarsat demonstration program, the satellite equipment is located on two satellites. The first is the Soviet Cosmos 1383 launched in June 1982. The second is the U.S. NOAA 8 launched in March 1983. Both are in polar orbits at about 400 to 550 nmi altitude. The two satellites are compatible. Both retransmit received signals at 1544.5 MHz.

There are three Sarsat ground stations each in the U.S. and U.S.S.R and one each in France and Canada. Each station can receive signals from either satellite whenever it is in view. The stations process the signal to

determine the location of the transmission. Location accuracy is about 12 nmi with the older transmitters, and better than 2 nmi with the new 406-MHz transmitters. In addition, processing for the new transmitters is simple enough to be done in a satellite. The satellite would then repeatedly transmit its position estimate. This will allow the system to be used even when the satellite is not simultaneously in view of the transmitter and the ground station.

The Sarsat demonstration began with the Cosmos 1383 launch. The first rescue supported by the satellite occurred in Canada in September 1982. Since then both satellites have aided various rescue attempts. The speed of the Sarsat aided rescues is credited with saving several lives. The system will be extended with equipment to be launched on additional Cosmos and NOAA satellites.

9. INTO THE 1990s

Without a doubt the field of communication satellites will continue to grow. Current domestic, regional, international, and miltary systems will all introduce new generations of satellites. The slowest growth will be in the military systems. Domestic and regional systems will probably continue the rapid growth which began about 1980. The domestic systems will include both dedicated satellites and Intelsat leases. Both the Intelsat and Inmarsat international systems will also grow. In addition, several organizations in the U.S. and Britain (Unisat) have proposed trans-Atlantic satellites, which to some extent would compete with Intelsat. This is a subject of political and legal debate now, but by the early 1990s there may be a competitor to Intelsat in operation.

Probably the largest new application in the next ten years will be direct broadcast satellites. The emphasis will be television broadcasting, but radio broadcasting will also be implemented. Relatively low power direct broadcast has already been tested with CTS and Anik B, and will be in use beginning in 1984 in the U.S. and Canada, and in 1985 in Australia. High power direct broadcasting will begin by 1986 with the TV-Sat and TDF in Europe and STC in the U.S. The number of satellites, the capability of each, and the number of countries using them should grow slowly in the late 1980s but quicken by the 1990s.

Another new application is mobile communications. The maritime mobile use of satellites is already well established. It is likely that Inmarsat will provide some service to aircraft with their second generation satellites at the end of this decade. Studies of land mobile communications are progressing in the U.S. and Canada, and satellite concepts have been proposed. Land mobile communications satellites, using frequencies near 900 MHz, should be in orbit at the beginning of the 1990s. This application may require development of large (e.g., 50-ft diameter) deployable satellite antennas.

To keep pace with increasing capacity demands, new features will be brought into satellite and system designs. The 1970s saw a relatively full exploitation of the 4- and 6- GHz bands, and the 1980s should produce the same for the 10- to 14-GHz bands. Although use of the 20- and 30-GHz bands has begun with the Japanese CS, large scale use of these bands will occur in the 1990s after the preliminary investigations with L-Sat, Italsat, and ACTS. In addition, experiments in the 40- and 50-GHz bands will be conducted in the early 1990s.

Antenna evolution will also contribute to increased capacity. Shaped beams, using multiple feed horns, have been used for several years, with Intelsat having the most advanced designs. These antennas will continue to increase in sophistication. The use of spot beams will grow and their beamwidth will decrease, leading to greater frequency reuse. Italsat, in 1987, will be the first to use multiple spot beams in one country. By the 1990s there may be satellites which cover the U.S. with dozens of independent spot beams. Another concept which has been studied is a scanning spot beam. This will be tested on ACTS and may be in use by the early 1900s.

The use of signal processors in satellites is another design step that will provide capacity growth. The processing can include switch matrices, either IF or baseband, which operate at a TDMA burst rate; demodulation and remodulation; demultiplexing and multiplexing of bit streams; coding and decoding; and routing of messages by reading headers. Early applications of these techniques will be on Intelsat VI, L-Sat, Italsat, and ACTS.

Operational use of intersatellite links began in 1983 with TDRS. The use of these links between synchronous altitude satellites has been studied for several years. However, their use will not occur until sometime in the 1990s. Potential benefits include positioning of satellites to improve ground elevation angles or to avoid crowded sections of the orbit, interconnecting widely spaced satellites to avoid double hop links, and interconnection of various types of satellites (e.g., mobile satellite to Intelsat) to provide more direct or flexible routing of links.

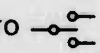
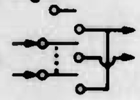
Enhancements of transmission techniques will also contribute to improved capacity. This covers modulation, coding, bandwidth compression and multiple access methods. Ground hardware plays the predominant role here, and application of available technology will be more significant than development of new technology. Nevertheless, developments will continue and will eventually be brought into use. The most activity will probably be in the area of voice processing to increase the number of voice circuits per unit bandwidth. Specific techniques which are already used occasionally, but should see significant use by the 1990s include digital speech interpolation, companding, delta modulation, and voice encoding. In addition, video bandwidth compression techniques will be important, both for full rate and slow scan transmissions. Also, use of TDMA will increase, and modulation formats with improved spectral efficiency will be applied to operational systems.

Spacecraft technology will progress to support larger or more complex communication subsystems. A major effort at present is in large lightweight solar arrays which can provide several kilowatts of power. These are most necessary for broadcast satellites. Nickel hydrogen batteries will be flown on several satellites in the next year, and could displace nickel cadmium batteries in most satellites by the 1990s. In propulsion subsystems, several satellite designs are incorporating unified bipropellant systems and/or electrothermal thrusters. Both provide improved performance to weight ratios. The next step will be electric propulsion for stationkeeping which will come into use sometime in the 1990s. Attitude control accuracies are being improved to satisfy requirements for more accurate antenna pointing, while at the same time coping with the motions of large flexible appendages. Whereas ± 0.1 deg pointing characterized the 1970s, ± 0.05 deg is not unusual now and another factor of two reduction should occur by 1990. The major contributor to the improvement will be the use of satellite receivers which track ground based beacons. Structurally, graphite composites and beryllium are already in common use where low weight and stiffness are important. The composites also have very low thermal expansion coefficients. The mechanical challenge of future communication satellites will probably be in ever larger antennas and their deployment and steering mechanisms.

Large space platforms have been discussed over the past five years. Sizes as large as 200 ft have been considered, with each platform accommodating many communication subsystems. As an alternative, clusters of conventional satellites, joined by intersatellite links, have been proposed. While both concepts have their merits, they seem to belong to the late nineties rather than in the coming ten years.

BLOCK DIAGRAM SYMBOLS

In Sections 3 through 8, communication subsystem block diagrams have been included for most of the satellites discussed. These diagrams are relatively simple, primarily showing antennas and diplexers, amplification, frequency conversion, and channel switching and combining. The following symbols are common to all the block diagrams; any specialized symbols are defined in the figure where they occur.

▷	AMPLIFIER (type not specified)
P	PARAMETRIC AMPLIFIER
T	TRANSISTOR AMPLIFIER
TD	TUNNEL DIODE AMPLIFIER
TW	TRAVELING WAVE TUBE AMPLIFIER
⊗	MIXER
S	SWITCH: EQUIVALENT TO 
S	SWITCH: EQUIVALENT TO 
C	CHANNEL COMBINER
H	FOUR-PORT HYBRID
D	DIPLEXER
F	FILTER
LIM	LIMITER
7250	FREQUENCY IN MHz
1 3 5	CHANNEL NUMBERS
50 kHz	BANDWIDTH
↑	INDICATES INPUT TO MIXER FROM LOCAL OSCILLATOR
2/3	SWITCH NETWORK — CONNECTS THE TWO INPUTS TO ANY TWO DISTINCT OUTPUTS
3/2	SWITCH NETWORK — CONNECTS ANY TWO INPUTS TO DISTINCT OUTPUTS
P	POWER SPLITTING NETWORK
▯	A SWITCH MATRIX, WITH MORE THAN 3 INPUTS OR OUTPUTS, WHICH CAN FORM MANY DIFFERENT ONE-TO-ONE INTERCONNECTIONS OF ITS INPUT AND OUTPUT PORTS. EXCESS INPUT OR OUTPUT PORTS ARE TERMINATED.

APPENDIX B

ABBREVIATIONS AND ACRONYMS

The following list provides the definitions of abbreviations and acronyms used in this report.

ACTS	Advanced Communications Technology Satellite (NASA)
ADCSP	Advanced Defense Communication Satellite Program
AFSATCOM	Air Force Satellite Communications
AM	Amplitude modulation
Amsat	Radio Amateur Satellite Corporation
APPLE	Ariane Passenger Payload Experiment (India)
Arabsat	Arab Space Communications Organization
ARPA	Advanced Research Projects Agency
ASC	American Satellite Corporation
ASEAN	Association of Southeast Asian Nations
AT&T	American Telephone and Telegraph Company
ATS	Applications Technology Satellite
AW	Advanced Westar
BAPTA	Bearing and Power Transfer Assembly
BFN	Beam forming network
bps	Bits per second
BS (or BSE)	Medium Scale Broadcasting Satellite for Experimental Purpose (Japan); BS2 is the operational Japanese Broadcasting Satellite
BSS	Broadcasting-Satellite Service
BTL	Bell Telephone Laboratories
CAS	Cooperative Applications Satellite

CCIR	From the French for International Radio Consultative Committee
CDMA	Code division multiple access
CIFAS	Consortium Industriel Franco-Allemand pour le satellite Symphonie (France-Germany)
CML	A joint venture of Comsat General, MCI, and Lockheed Aircraft, called CML Satellite Corporation
CNES	Centre National d'Etudes Spatiales (France)
CNR	Consiglio Nazionale della Richerche (Italian National Research Council)
Comsat	Communications Satellite Corporation
CONUS	Continental United States
CS	Japanese Communication Satellite
CTS	Communications Technology Satellite (now known as Hermes in Canada)
CW	Continuous Wave
DATS	Despun Antenna Test Satellite
dB	Decibel
dBW	Decibel Watt
DC	Direct current
DCA	Defense Communications Agency
DFVLR	Deutsche Forschungs und Versuchsanstalt für Luft-und Raumfahrt (W. Germany)
DNA	Defense Nuclear Agency
DoD	Department of Defense
Domsat	Domestic communications satellite
DPSK	Differential phase shift keying
DQPSK	Differential quadriphase shift keying
DSCS	Defense Satellite Communication System

EBU	European Broadcasting Union
EC	Earth Coverage
ECS	Experimental Communications Satellite (Japan) European Communication Satellite
ERP	Effective radiated power
ESA	European Space Agency
ESRO	European Space Research Organization
ETS-II	Engineering Test Satellite - Type II (Japan)
Eutelsat	European Telecommunications Satellite Organization
FCC	Federal Communications Commission
FDM	Frequency division multiplexing
FDMA	Frequency division multiple access
FET	Field effect transistor
FLTSATCOM	Fleet Satellite Communications
FM	Frequency modulation
FSK	Frequency shift keying
FTV	Frontier television (terminal) (Canada)
GDA	Gimballed dish antenna
GEOS	Geodynamics Experimental Ocean Satellite
GGTS	Gravity Gradient Test Satellite
GHz	Gigahertz
GOES	Geostationary Operational Environmental Satellite
GSat	GTE Satellite Corporation
G/T	Gain-to-noise-temperature ratio
GTE	General Telephone and Electronics
HCI	Hughes Communications, Inc.

HF	High frequency
HR	Heavy route (terminal) (Canada)
H-Sat	Heavy Communications Satellite (Europe) (now L-Sat)
Hz	Hertz
IDCSP	Initial Defense Communication Satellite Program
IDSCS	Initial Defense Satellite Communication System
IF	Intermediate frequency
IFRB	International Frequency Registration Board
IMCO	Intergovernmental Maritime Consultative Organization
Inmarsat	International Maritime Satellite Organization
Intelsat	International Telecommunication Satellite Organization
ISRO	Indian Space Research Organization
ITU	International Telecommunication Union
ITV	Instructional television (ATS 6)
IUS	Inertial Upper Stage
K	Kelvin
kbps	Kilobits per second
kHz	Kilohertz
KSA	K-band single access (TDRSS)
kWh	Kilowatt hours
LAM	Liquid apogee motor
LES	Lincoln Experimental Satellite
LHC	Left hand circular (polarization)
L-Sat	Large Telecommunications Satellite (Europe)
MA	Multiple access (TDRSS)
Marecs	Maritime European Communication Satellite

Marots	Maritime Orbital Test Satellite
MB	Multibeam
Mb	Megabit
MBA	Multibeam Antenna
Mbps	Megabits per second
MCI	Microwave Communications, Inc.
MCS	Maritime communication subsystem (Intelsat V)
MESH	A West European industrial consortium
MHz	Megahertz
MIT	Massachusetts Institute of Technology
MMD	Mean mission duration
MTBF	Mean time before failure
MTTF	Mean time to failure
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency (Japan)
NATO	North Atlantic Treaty Organization
NiCd	Nickel cadmium (battery)
NiH_2	Nickel hydrogen (battery)
nmi	Nautical mile
NOAA	National Oceanic and Atmospheric Administration
NTC	Northern telecommunication (terminal) (occasionally named Medium Route) (Canada)
NTV	Network television (terminal) (Canada)
OFT	Orbital flight test
ORBIS	Orbiting Radio Beacon Satellite
Oscar	Orbiting Satellite Carrying Amateur Radio

OTS	Orbital Test Satellite (Europe)
OV	Orbiting vehicle
PAM	Perigee assist motor Pulse amplitude modulation
PBS	Public Broadcasting Service
PCM	Pulse code modulation
PEACESAT	Pan Pacific Education and Communication Experiments by Satellite
PKM	Perigee kick motor
PLACE	Position Location and Aircraft Communication Experiment (ATS 6)
PM	Phase modulation
PNG	Papua New Guinea
PSK	Phase shift keying
QPSK	Quadriphase shift keying
RARC	Regional Administrative Radio Conference
RCA	Radio Corporation of America
RCS	Reaction control subsystem
RF	Radio frequency
RFI	Radio frequency interference
RHC	Right hand circular (polarization)
rpm	Revolutions per minute
RS	Amateur radio satellites (U.S.S.R.)
RTG	Radioisotope thermoelectric generator
RTV	Remote television (terminal) (Canada)
SAMSO	Space and Missile Systems Organization (U.S. Air Force) (Now Space Division)
SARSAT	Search and Rescue Satellite Aided Tracking

SBS	Satellite Business Systems
SCF	Satellite Control Facility (U.S. Air Force)
SCORE	Signal Communication by Orbiting Relay Equipment
SCPC	Single channel per carrier
SCT	Single channel transponder (AFSATCOM)
SGLS	Space-Ground Link Subsystem (U.S. Air Force)
SHF	super high frequency
Sirio	From the Italian words for Italian Industrial Research Satellite Organization
SITE	Satellite instructional television experiment (ATS 6)
SMS	Synchronous Meteorological Satellite
SPADE	Single channel per carrier, Pulse code modulation, multiple Access, Demand-assigned Equipment
SPCC	Southern Pacific Communications Corporation
SSA	S-band single access (TDRSS)
SSMA	Spread spectrum multiple access
SS-TDMA	Satellite-switched TDMA
STDN	Spaceflight Tracking and Data Network
STEP	Satellite Telecommunications Experimental Project (India)
STP	Space Test Program (U.S. Air Force)
STW	Shiyan Tongxin Weixing (experimental communications satellite) (China)
Tacsat	Tactical Communications Satellite
TDA	Tunnel diode amplifier
TDF	Telediffusion de France
TDMA	Time division multiple access
TDRS(S)	Tracking and Data Relay Satellite (System)

TETR	(see TTS)
TR	Thin route (terminal) (Canada)
TRUST	Television Relay Using Small Terminals (ATS 6)
TT&C	Telemetry, tracking, and command
TTS	Test and Training Satellite
TWT	Traveling wave tube
TWTA	Traveling wave tube amplifier
UHF	Ultrahigh frequency
VHF	Very high frequency
WARC	World Administrative Radio Conference

APPENDIX C

THE ITU AND INTERNATIONAL FREQUENCY ALLOCATIONS

(Refs. 788-796)

C.1 THE ITU

The International Telecommunication Union (ITU) is a specialized agency of the United Nations. At present about 150 nations are ITU members, including all the major world powers and all countries which use satellite communications. The purpose of the ITU is to promote international cooperation in the efficient use of telecommunications. Activities toward this end, related to frequency allocations and their use, are to:

a. prepare regulations,

b. allocate the radio frequency spectrum,

c. register radio frequency assignments and geostationary satellite longitudes,

d. coordinate efforts to eliminate harmful interference, and

e. adopt resolutions and formulate recommendations concerning telecommunications matters.

The governing document of the ITU is the International Telecommunication Convention. The highest decision-making body is the Plenipotentiary Conferences. The work of the ITU is done in both periodic international conferences and by permanent agencies with staffs at Geneva.

The ITU Radio Regulations include, among other things, the Table of Frequency Allocations, procedures for notification, registration, and coordination of new or modified uses of the frequency spectrum, and provisions to limit interference between users of the frequency allocations. The Regulations, when ratified by the member nations, have the legal force of a treaty.

Revision of the Radio Regulations is carried out in general and special World Administrative Radio Conferences (WARCs) and in Regional Administrative Radio Conferences (RARCs). A general WARC was held in 1979 and was authorized to consider a complete revision of the Radio Regulations. The previous general WARC was in 1959 and the next is expected about 1999. Specialized WARCs and RARCs occur more often. Each is chartered to address revisions of the Radio Regulations concerning a specific topic. Conferences that considered satellite matters have included the WARC for Space Telecommunications (1971), WARC for Satellite Broadcasting (1977), and the RARC for Satellite Broadcasting in Region 2 (1983). A two-session Space Systems WARC in 1985 and 1987 will consider use of the synchronous orbit and relevant frequency allocations.

The International Frequency Registration Board (IFRB) is one of the permanent ITU agencies. It is responsible for maintaining the international list of frequency assignments for both earth and space stations. This responsibility includes the process of notification, coordination, and registration of new and modified frequency assignments, including those for space systems. The process is basically the following:

a. Several years before a new system comes into use, the national administration notifies the IFRB of its technical characteristics.

b. These characteristics are published in the weekly IFRB circular.

c. Any administration concerned about potential harmful interference from the proposed system may make comments to, and request coordination with, the notifying administration.

d. The coordination may result in modifications to the proposed system, and if necessary thereafter, modifications to existing systems.

e. The IFRB reviews the proposed system in light of the Radio Regulations, current spectrum usage, and the results of steps c and d.

f. If all of the above are satisfactory, the IFRB registers the system by publication in the Master International Frequency Register, which is intended to guarantee that it will not be subject to harmful interference from systems which have yet to be registered.

The CCIR* is another permanent ITU agency. It studies technical and operational questions in the field of radio communications. The CCIR is organized into more than a dozen specialized study groups. Those most relevant to the satellite communications are:

Group 1 - Spectrum Utilization and Monitoring,

Group 4 - Fixed Service Using Communication Satellites, and

Group 9 - Coordination and Frequency Sharing Between Systems in the Fixed-Satellite Service and Terrestrial Radio-Relay Systems.

In addition, the Mobile and Broadcasting Services groups study matters related to satellites. Each study group, which has representatives from any nation interested in its work, meets once or more a year. Much of the group's work depends on inputs from national study groups. The U.S. has active national study groups corresponding to each of the CCIR groups. Approximately every four years, the entire CCIR has a Plenary Assembly. The assembly considers new recommendations, modifies existing recommendations, prepares resolutions, and considers the study program for each group for the next four years. Recommendations, reports, and resolutions are published after every Plenary Assembly. Although the CCIR outputs are not binding, they are often adopted by international or national agencies as technical standards. In addition, the CCIR has preparatory meetings six months to a year before WARCs.

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*From the French for International Radio Consultative Committee.

C.2 FREQUENCY ALLOCATIONS

The Radio Regulations define 37 radio services, and specify which services are allowed to use each portion of the spectrum between 9 kHz and 275 GHz. The tables in this appendix show the allocations applicable to the satellites described in this report, for frequencies up to 100 GHz. Table C-1 shows the first allocations, which were made in 1963. It is provided for comparison with the current allocations listed in Table C-2. Nations may modify the allocations table for use within their own boundaries. In the U.S. this has occured; a typical modification is the split of an allocation into government and non-government sub-bands. Furthermore, each nation authorizes, uses, and assigns frequencies within its own jurisdiction. In the U.S., the Interdepartment Radio Advisory Committee controls Federal government use of the spectrum and the Federal Communications Commission controls other uses.

The allocations in Table C-2 are separated by the service to which they apply. (Fixed-satellite service and mobile-satellite service refer to whether the terminals, not the satellites, are fixed or mobile.) Some links qualify to use allocations for two types of systems. For example, in a system serving mobile terminals, the link between a satellite and a fixed terminal (e.g., a shore station in a maritime satellite system) may use either the fixed terminal or mobile terminal system allocations. When an allocation is not specified for uplinks or downlinks, it can be used for either or both. The Region column indicates the availability of the allocation by the three ITU regions (see Figure C-1). A blank in this column indicates worldwide availability. The status column indicates whether the allocation is primary, secondary, or by means of a footnote. This status determines the priority of the various allocations in interference questions. The Power Limit column indicates allocations where the power density of a downlink is limited. The actual limitations are given in Table C-3. The Notes column references the notes at the end of Table C-2 that give more information about specific allocations. However, this table and its notes do not contain all the details that are in the ITU frequency allocation table.

Table C-1. Initial Frequency Allocations Made in 1963

Downlink (MHz)	Uplink (MHz)
3400 - 3700	4400 - 4700
	5725 - 5925
3700 - 4200	5925 - 6425
7250 - 7300	7975 - 8025
7300 - 7750	7900 - 7975 8025 - 8400

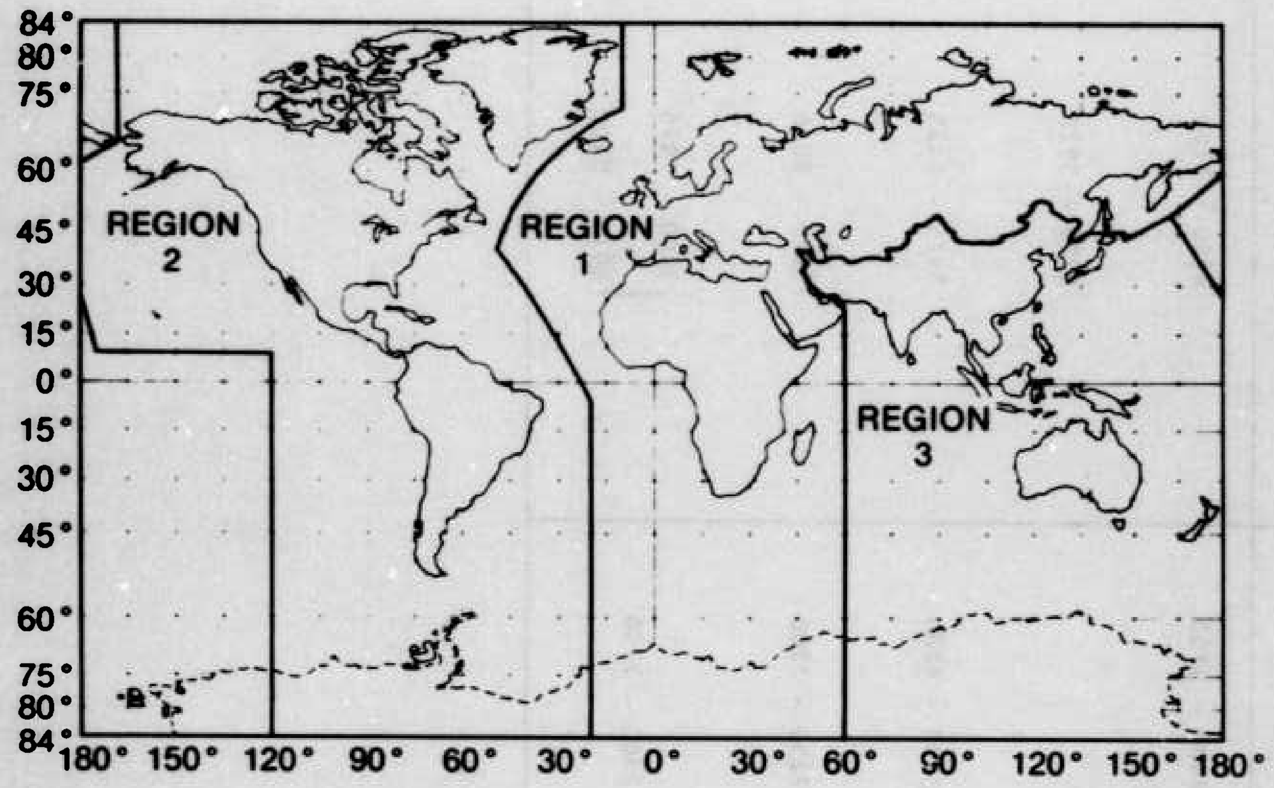

Figure C-1. ITU Regions

Table C-2. Current Frequency Allocations

Downlink[a]	Uplink[a]	Region[b]	Status[c]	Power Limit[d]	Notes
FIXED-SATELLITE SERVICE (FSS)					
2500-2535 MHz		3	P	Yes	e.
2500-2655		2	P	Yes	e.
2655-2690		2	P	Yes	e.
	2655-2690	3	P		e.
3400-4200			P	Yes	
4500-4800			P	Yes	
5000-5250			F		f.
	5725-5850	1	P		
	5850-7075		P		
7250-7750			P	Yes	
	7900-8400		P		
	10.7-11.7 GHz	1	P	Yes	g.
10.7-11.7			P		
11.7-12.2		2	P		h.
12.2-12.5		3	F	Yes	h.
12.2-12.7		2	F	i.	i.
12.5-12.75		1	P	Yes	
12.5-12.75		3	P	Yes	
	12.7-12.75	2	P		
	12.75-13.25		P		
	14.0-14.5		P		j.
	14.5-14.8	k,2,3	P		k.
	17.3-18.1		P		g.
17.7-19.7			P	Yes	
19.7-21.2			P		
	27.0-27.5	2,3	P		
	27.5-31.0		P		
31.8-33.8		1.	F		l.
	37.0-39.0	1.	F		l.
37.5-40.5			P	Yes	
	42.5-43.5		P		
	47.2-50.2		P		m.
	50.4-51.4		P		
	71.0-75.5		P		
81.0-84.0			P		
	92.0-95.0		P		

Table C-2. Current Frequency Allocations (Continued)

<table>
<tr><th>Downlink[a]</th><th>Uplink[a]</th><th>Region[b]</th><th>Status[c]</th><th>Power Limit[d]</th><th>Notes</th></tr>
<tr><td colspan="6">MOBILE-SATELLITE SERVICE (MSS)[n]</td></tr>
<tr><td colspan="2">235-322 MHz</td><td></td><td>F</td><td></td><td>o.</td></tr>
<tr><td colspan="2">335.4-399.9</td><td></td><td>F</td><td></td><td>o.</td></tr>
<tr><td></td><td>406.0-406.1</td><td></td><td>P</td><td></td><td>p.</td></tr>
<tr><td></td><td>608-614</td><td>2</td><td>S</td><td></td><td></td></tr>
<tr><td colspan="2">806-890</td><td>q,2,3</td><td>F</td><td></td><td>r.</td></tr>
<tr><td colspan="2">942-960</td><td>q,3</td><td>F</td><td></td><td>r.</td></tr>
<tr><td>1530-1544</td><td></td><td></td><td>P</td><td></td><td></td></tr>
<tr><td>1544-1545</td><td></td><td></td><td>P</td><td></td><td>s.</td></tr>
<tr><td>1545-1559</td><td></td><td></td><td>P</td><td></td><td></td></tr>
<tr><td></td><td>1626.5-1645.5</td><td></td><td>P</td><td></td><td></td></tr>
<tr><td></td><td>1645.5-1646.5</td><td></td><td>P</td><td></td><td>s.</td></tr>
<tr><td></td><td>1646.5-1660.5</td><td></td><td>P</td><td></td><td></td></tr>
<tr><td>2500-2535</td><td></td><td>3</td><td>F</td><td>Yes</td><td>r.</td></tr>
<tr><td></td><td>2655-2690</td><td>3</td><td>F</td><td></td><td>r.</td></tr>
<tr><td>7250-7375</td><td></td><td></td><td>F</td><td>Yes</td><td></td></tr>
<tr><td></td><td>7900-8025</td><td></td><td>F</td><td></td><td></td></tr>
<tr><td></td><td>14.0-14.5 GHz</td><td></td><td>F</td><td></td><td></td></tr>
<tr><td>19.7-20.2</td><td></td><td></td><td>S</td><td></td><td></td></tr>
<tr><td>20.2-21.2</td><td></td><td></td><td>P</td><td></td><td></td></tr>
<tr><td></td><td>29.5-30.0</td><td></td><td>S</td><td></td><td></td></tr>
<tr><td></td><td>30.0-31.0</td><td></td><td>P</td><td></td><td></td></tr>
<tr><td>39.5-40.5</td><td></td><td></td><td>P</td><td>Yes</td><td></td></tr>
<tr><td colspan="2">43.5-47.0</td><td></td><td>P</td><td></td><td></td></tr>
<tr><td></td><td>50.4-51.4</td><td></td><td>S</td><td></td><td></td></tr>
<tr><td colspan="2">66.0-71.0</td><td></td><td>P</td><td></td><td></td></tr>
<tr><td></td><td>71.0-74.0</td><td></td><td>P</td><td></td><td></td></tr>
<tr><td>81.0-84.0</td><td></td><td></td><td>P</td><td></td><td></td></tr>
<tr><td colspan="2">95.0-100.0</td><td></td><td>P</td><td></td><td></td></tr>
<tr><td colspan="6">BROADCASTING-SATELLITE SERVICE (BSS)[t]</td></tr>
<tr><td>620-790 MHz</td><td></td><td></td><td>F</td><td></td><td></td></tr>
<tr><td>2500-2690</td><td></td><td></td><td>P</td><td>Yes</td><td>e.</td></tr>
<tr><td>11.7-12.5 GHz</td><td></td><td>1</td><td>P</td><td></td><td></td></tr>
<tr><td>11.7-12.2</td><td></td><td>2</td><td>F</td><td></td><td>u.</td></tr>
<tr><td>11.7-12.2</td><td></td><td>3</td><td>P</td><td></td><td></td></tr>
<tr><td>12.2-12.7</td><td></td><td>2</td><td>P</td><td></td><td></td></tr>
<tr><td>12.5-12.75</td><td></td><td>3</td><td>P</td><td></td><td></td></tr>
<tr><td>22.5-23.0</td><td></td><td>2,3</td><td>P</td><td></td><td></td></tr>
<tr><td>40.5-42.5</td><td></td><td></td><td>P</td><td></td><td></td></tr>
<tr><td>84.0-86.0</td><td></td><td></td><td>P</td><td></td><td></td></tr>
</table>

Table C-2. Current Frequency Allocations (Continued)

<table>
<tr><th>Downlink[a]</th><th>Uplink[a]</th><th>Region[b]</th><th>Status[c]</th><th>Power Limit[d]</th><th>Notes</th></tr>
<tr><td colspan="6">INTERSATELLITE SERVICE (ISS)</td></tr>
<tr><td colspan="2">5000-5250 MHz</td><td></td><td>P</td><td></td><td>f.</td></tr>
<tr><td colspan="2">15.4-15.7 GHz</td><td></td><td>P</td><td></td><td>f.</td></tr>
<tr><td colspan="2">22.5-23.5</td><td></td><td>P</td><td></td><td></td></tr>
<tr><td colspan="2">32.0-33.0</td><td></td><td>P</td><td></td><td></td></tr>
<tr><td colspan="2">54.25-58.2</td><td></td><td>P</td><td></td><td></td></tr>
<tr><td colspan="2">59-64</td><td></td><td>P</td><td></td><td></td></tr>
<tr><td colspan="6">AMATEUR-SATELLITE SERVICE</td></tr>
<tr><td colspan="2">7.0-7.1 MHz</td><td></td><td>P</td><td></td><td></td></tr>
<tr><td colspan="2">14.0-14.25</td><td></td><td>P</td><td></td><td></td></tr>
<tr><td colspan="2">18.068-18.168</td><td></td><td>P</td><td></td><td></td></tr>
<tr><td colspan="2">21.0-21.45</td><td></td><td>P</td><td></td><td></td></tr>
<tr><td colspan="2">24.89-24.99</td><td></td><td>P</td><td></td><td></td></tr>
<tr><td colspan="2">28.0-29.7</td><td></td><td>P</td><td></td><td></td></tr>
<tr><td colspan="2">144-146</td><td></td><td>P</td><td></td><td></td></tr>
<tr><td colspan="2">435-438</td><td></td><td>F</td><td></td><td>o.</td></tr>
<tr><td></td><td>1260-1270</td><td></td><td>F</td><td></td><td>o.</td></tr>
<tr><td colspan="2">2400-2450</td><td></td><td>F</td><td></td><td>o.</td></tr>
<tr><td colspan="2">3400-3410</td><td>2,3</td><td>F</td><td></td><td>o.</td></tr>
<tr><td></td><td>5650-5670</td><td></td><td>F</td><td></td><td>o.</td></tr>
<tr><td>5830-5850</td><td></td><td></td><td>F</td><td></td><td></td></tr>
<tr><td colspan="2">10.45-10.5 GHz</td><td></td><td>S</td><td></td><td></td></tr>
<tr><td colspan="2">24.0-24.05</td><td></td><td>P</td><td></td><td></td></tr>
<tr><td colspan="2">47.0-47.2</td><td></td><td>P</td><td></td><td></td></tr>
<tr><td colspan="2">75.5-76.0</td><td></td><td>P</td><td></td><td></td></tr>
<tr><td colspan="2">76.0-81.0</td><td></td><td>S</td><td></td><td></td></tr>
</table>

Table C-2. Current Frequency Allocations (Continued)

Notes

a. A frequency band centered in these two columns may be used for both uplinks and downlinks.

b. A blank indicates worldwide applicability. Numbers indicate applicability in some regions, which are defined in Figure C-1.

c. P = Primary, S = Secondary, F = Footnote. Secondary uses must not interfere with primary uses nor claim protection against interference from primary uses. Footnotes imply particular restrictions; see notes. Also, secondary or footnote status implies a power limit.

d. Power limit: if yes, see Table C-3.

e. National and regional systems only.

f. Only when used in conjunction with aeronautical radio navigation and/or aeronautical mobile service.

g. Only for broadcast satellite feeder links.

h. National and subregional systems only.

i. BSS is the primary use. FSS must not cause more interference nor require more protection than the BSS.

j. May be used outside Europe for broadcast satellite feeder links.

k. Broadcast satellite feeder links only and outside Europe only.

l. Japan only and only until 31 December 1990.

m. 47.2 to 49.2 GHz is primarily for broadcast satellite feeder links.

n. Some allocations restrict use to one or more of the MSS subsets: maritime-MSS, aeronautical-MSS, land-MSS.

o. Must not cause harmful interference to primary or secondary uses.

p. Solely for low power beacons for emergency position location.

q. Only Norway and Sweden in region 1.

Table C-2. Current Frequency Allocations (Continued)

Notes

r. Limited to operations within national boundaries.

s. Solely for distress and safety uses.

t. Uplinks are normally in FSS allocations.

u. FSS is the primary use. BSS limited to 53 dBW ERP. BSS must not cause more interference nor require more protection than the FSS.

Table C-3. Maximum Power Density on the Earth's Surface, dBW/m^2 (measured with the specified bandwidth)

Allocation	Elevation			Bandwidth
	$0^\circ - 20^\circ$	$20^\circ \leq \theta \leq 60^\circ$	$60^\circ - 90^\circ$	
620 - 790 MHz	-129	$-129 + \frac{2}{5}(\theta - 20)$	-113	
	$0^\circ - 5^\circ$	$5^\circ \leq \theta \leq 25^\circ$	$25^\circ - 90^\circ$	
2500 - 2690	-152	$-152 + \frac{3}{4}(\theta - 5)$	-137	4 kHz
3400 - 4200 4500 - 4800 7250 - 7750	-152	$-152 + \frac{\theta - 5}{2}$	-142	4 kHz
10.7 - 11.7 GHz	-150	$-150 + \frac{\theta - 5}{2}$	-140	4 kHz
12.2 - 12.5 (Region 3) 12.5 - 12.75 (Regions 1 and 3)	-148	$-148 + \frac{\theta - 5}{2}$	-138	4 kHz
17.7 - 19.7 37.5 - 40.5	-115	$-115 + \frac{\theta - 5}{2}$	-105	1 MHz

These power density limits may be exceeded on the territory of any country with its approval.

APPENDIX D

TELEMETRY, TRACKING, AND COMMAND SUBSYSTEMS

D.1 INTRODUCTION

All satellites have some form of telemetry, tracking, and command (TT&C) subsystem to provide control and monitoring of satellite status and to obtain data from which the satellite position can be computed. The major types of TT&C subsystems currently in use by communication satellites are described in this appendix.

D.2 INTELSAT/DOMSAT

This type of subsystem is used by Intelsat and by the U.S. domestic satellites and those domestic satellites built in the U.S. for other countries. This type of system is described as "in-band" because the TT&C frequencies are within the frequency bands allocated for communications. Intelsat TT&C frequencies are near the center of the band (6168 to 6182 MHz for command and 3945 to 3955 MHz for telemetry). The domsats use either the top or bottom 5 MHz of the communications band (i.e., 5925 to 5930 or 6420 to 6425 MHz for command and 3700 to 3705 or 4195 to 4200 MHz for telemetry). As a result of this frequency choice, most radio frequency TT&C functions are handled by communication subsystem components. During normal operations TT&C signals are routed through communication subsystem antennas. Broad coverage "omnidirectional" antennas are used from launch vehicle separation through deployment and in the event of loss of signals through the communications antennas.

The basic command structure uses three tones for transmission of information, namely, one, zero, and execute tones. The information FSK modulates the tones. Some systems add one to four additional command tones, usually for analog commands or pilot tones for spin rate or antenna pointing

control on dual-spin satellites. The tone set frequency modulates the command carrier. The size of the command sets varies up to about 500 commands.

The telemetry portion of the subsystem has two separate sets of equipment transmitting on separate frequencies. Each set of equipment can be commanded to handle either digital or analog telemetry. Analog telemetry frequency modulates a subcarrier. Two digital formats are used, either PCM/PSK or PAM/FM modulation of a subcarrier. In all cases the subcarrier phase modulates the carrier.

Tracking is accomplished by sequentially modulating an uplink carrier with four tones that the satellite retransmits on a downlink. The tones vary in frequency from 35 Hz to 27.8 kHz. The range to the satellite is determined by measuring the tone phase shift during the round trip transmission. Successively higher tone frequencies provide increased accuracy, with the lower tones used to resolve ambiguities that occur with the higher tones. The ranging signal can be transmitted using the command and telemetry carriers, but is typically transmitted through one of the communication transponders during on-orbit operations.

The SBS and Anik C satellites use the same TT&C subsystem. However, their communication subsystems operate in the 12- and 14-GHz bands rather than in the 4- and 6-GHz bands. They use 4- and 6-GHz transmissions through omnidirectional antennas prior to orbital deployment, and 12- and 14-GHz transmissions through the communication subsystem thereafter.

D.3 SPACE-GROUND LINK SUBSYSTEM

The Space-Ground Link Subsystem (SGLS) is used for TT&C for all operational military communication satellites of the U.S., Britain, and NATO. These satellites use frequencies between 7250 and 8400 MHz for communications. SGLS is entirely separate, using 1760 to 1840 MHz for commands and 2200 to 2300 MHz for telemetry. Each satellite is assigned to

one of 20 channels within these bands. In addition, most of the satellites also transmit telemetry on beacons in the 7250 to 7750-MHz communication band.

The SGLS command structure uses three tones: one, zero, and S. The S tone is transmitted during commanding whenever either of the other tones is not used. Only one tone is used at a time in a FSK format. The tones are amplitude-modulated with a synchronization signal and phase modulate the command carrier, a format designated FSK/AM/PM. The command signal transmission rate is usually 1000 baud, and the command sets vary in size from about 100 to 700 commands. All the satellites have provision for cryptographic security on the command link.

The DSCS III satellite has an additional "in-band" command capability. The uplink at approximately 8 GHz is received by the satellite and down converted to the SGLS frequency and handled by the SGLS equipment.

SGLS telemetry is almost always digital, although an analog capability is possible. The typical modulation format is PCM/PSK on a subcarrier that phase modulates the carrier. Telemetry rates are 250 or 1000 bps, with from 200 to almost 1000 points monitored.

Unlike other TT&C subsystems discussed in this appendix, SGLS uses a pseudorandom binary sequence to determine range. The sequence phase modulates the command carrier and is remodulated on the telemetry carrier by the satellite. The phase shift over the round trip path is used to compute range. The sequence bit rate is 1 Mbps.

D.4 LES-8 AND -9

The experimental satellites LES-8 and -9 were developed and are operated by the MIT Lincoln Laboratory for DoD. These satellites use a TT&C subsystem designed by Lincoln Laboratory.

The normal command link to a satellite is a FSK-modulated UHF carrier. Alternate command paths are via a K-band communication link, either from the ground terminal or on the crosslink from the other satellite. The commands are transmitted at about one per second and there are about 220 commands.

The primary telemetry link is at S-band - 2.24 GHz for one satellite and 2.25 for the other. The bit rate may be either 100 bps or 10 kbps. Alternate paths are a UHF downlink or (at 100 bps only) a K-band downlink or crosslink. About 800 telemetry points are monitored.

D.5 NASA

The NASA Spaceflight Tracking and Data Network (STDN) provides TT&C services in several frequency bands. All the ATS and CTS satellites as well as the Japanese ECS and ETS-II satellites used the VHF capability. Some European satellites have STDN compatible VHF TT&C for launch and orbital insertion and for backup during operations.

Command frequencies are in the 147- to 155- MHz band. Both PSK and FSK subcarrier formats are used, with phase modulation of the carrier. ATS 6 had a command set of 512 commands and a transmission rate of 128 or 1200 bps. The CTS had a total of 225 commands and a 1000-bps transmission rate. The Japanese ECS had a total of 168 commands and a transmission rate of 128 bps. ATS 6 had an alternate command path through a communications uplink at about 6 GHz.

Telemetry frequencies are assigned in the 136- to 138-MHz band. Typical modulation formats are PCM/PM or PCM/FM/PM. ATS 6 had two telemetry carriers at rates of about 400 bps. About 1050 telemetry points were monitored. CTS had a single carrier at 1536 bps with a total of 276 telemetry points. ECS had about 70 points and a telemetry rate of 250 bps.

The tracking scheme uses multiple tones in the same manner as the Intelsat system described above. The highest tone frequency is 20 kHz. The tones may be transmitted at the command and telemetry frequencies. ECS, however, did its ranging through a 4- and 6-GHz satellite transponder.

The Japanese CS satellite has a TT&C subsystem with two transmission bands. One is an in-band arrangement very similar to that of Intelsat. The other is compatible with STDN's S-band equipment, and uses 2.11 GHz for commanding and 2.2865 GHz for telemetry. In both cases, the command format is PCM/FSK/PM with a rate of 128 bps. The telemetry format is PCM/PSK/PM at a rate of 250 bps.

NASA TT&C services through TDRSS use a new format because the existing subcarrier modulation methods are inefficient for transmission through a relay satellite. Commands directly biphase modulate the carrier, and telemetry and other data directly modulate the carrier with either a biphase or quadriphase format. Ranging is by means of a binary pseudorandom code.

D.6 EUROPE

The European satellites use in-band TT&C, often with a VHF back-up. In some cases VHF is used until orbital insertion. Their communication bands are 4 and 6 GHz in some cases, 11 and 14 GHz in others. Formats are similar or identical to the Intelsat and NASA formats already described. The data rates and numbers of commands and telemetry points are all within the range of 100 to 1000, just as the great majority of cases previously described.

APPENDIX E

SATELLITE BEACONS FOR PROPAGATION RESEARCH

E.1 INTRODUCTION

The atmosphere can affect electromagnetic waves in several ways. Parameters that can be affected include amplitude, phase, polarization, and direction of propagation. The magnitude of each of these effects is dependent on several of the following factors: frequency, polarization, and elevation angle of the wave; terminal location and altitude; time of day and year; and the condition of the atmosphere. These disturbances need to be considered in the design of communication satellite systems. Therefore, they have been, and continue to be, studied in order to quantify them for use in communication link analyses.* In most cases the quantification is statistical rather than definitive; results are often specified by plotting link degradation versus the probability of exceeding the degradation.

In general, measurements of atmospheric effects that are made using horizontal paths cannot be accurately related to inclined earth-space paths. Therefore, an electromagnetic wave propagating obliquely through the atmosphere is necessary. The sun can be used for a source but only for a limited set of measurements because it is not a coherent emitter. Some amplitude statistics can be inferred from measuring the sky noise temperature without using any signal source. However, the most satisfactory and often the only way to measure atmospheric effects is to use a satellite-based signal source. This source may be a beacon generated on the satellite or a retransmission of a signal received from a ground terminal. Occasionally, ground-based signal sources and satellite receivers are used, with the received signal parameters telemetered to the ground.

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*These disturbances are also studied for the purpose of gaining knowledge about the composition and behavior of the atmosphere.

The following sections are a discussion of satellite beacons and transponders used in propagation research for communications engineering purposes. This discussion is divided into three sections in which three frequency bands are described.

E.2 BELOW 30 MHz

Early in the space age there was interest in low frequency earth-space links. This interest was the result of terrestrial use of frequencies below 30 MHz for long distance communications. Waves at these frequencies can propagate far beyond the horizon under some conditions. This feature is useful for long distance communication with satellites at low altitudes. However, as the space age progressed, the performance and reliability of satelliteborne microwave hardware improved greatly, and the use of the synchronous equatorial orbit was perfected. These two developments eventually overshadowed interest in the lower frequencies for almost all communications applications.

The majority of experiments in this frequency range were oriented toward atmospheric and ionospheric physics. Those oriented toward communications include ORBIS (1964), OV4-1 (1966), OV1-17 (1969), and an experiment on the Space Test Program (STP) satellite S74-2 (1976). UOSat, an amateur satellite launched in October 1981, has beacons at 7, 14, 21, and 28 MHz.

E.3 VHF AND UHF

Most experiments in the lower part of the VHF band, approximately 30 to 100 MHz, are scientific studies. Oscar 5, launched in 1970, had beacons at 29.45 and 144 MHz for communications measurements. The band between 225 and 400 MHz is important for military communication satellites, yet it is characterized by significant amplitude and phase fluctuations. Therefore, several communications related experiments have been conducted in this band.

These expermiments have made use of the communications transponders of several satellites including those of the ATS series and LES-5 and -6. Other measurements were made using the 254-MHz beacon on Tacsat and the 40-, 140-, and 360-MHz beacons on the ATS 6. LES-3 was a beacon satellite launched in 1965 specifically as a signal source for propagation measurements at approximately 240 MHz. The Defense Nuclear Agency (DNA) had an experiment on STP satellite P76-5 launched in 1976. This experiment transmitted signals at 138 MHz, 1.24 and 2.89 GHz, and at seven frequencies in the 378- to 448-MHz band.

E.4 ABOVE 10 GHz

Atmospheric effects in the 4- to 8-GHz bands are relatively mild. Measurements in this frequency range have been accomplished using the regular equipment on communication satellites. The need for more bandwidth is causing systems to be designed using allocated bands above 10 GHz. Above this frequency both atmospheric gases and rain can have significant effects on communication links. Many experiments are being conducted, particularly to quantify the attenuation and polarization effects of rain in the 10- to 30-GHz range of frequencies.

ATS 5 was the first satellite to have equipment for propagation measurements above 10 GHz. It was launched in 1969 and had an experiment with a 31.65-GHz uplink and a 15.3-GHz downlink. ATS 6 followed with a 13- and 18-GHz uplink experiment and a 20- and 30-GHz downlink experiment. The uplink experiment included terminals sited to study diversity as a means to overcome rain loss. The downlink experiment had three modes: an unmodulated carrier, a 1.4-GHz wide line spectrum, or retransmission of a modulated 6-GHz uplink. These experiments were used for several years in the U.S. and for one year in Europe while ATS 6 was stationed at 35°E longitude. The AT&T Comstar satellites had beacons at 19.04 and 28.56 GHz. The 28-GHz signal was modulated to produce sidetones at either ±264.4 or ±528.9 MHz and the 19-GHz signal was switched between orthogonal linear polarizations at a 1-kHz rate. ETS-II was a Japanese beacon satellite that operated over one year transmitting at 1.7, 11.5, and 34.5 GHz.

Several experimental communication satellites have been built to operate in the 10- to 30-GHz range. All of them are used to some extent in propagation tests. Sirio can be used for propagation measurements with both uplink and downlink signals, or for communication tests. It operates at 11.6 and 17.4 GHz. OTS operates in the 12- and 14-GHz bands. Of its five transponders, one is dedicated to propagation studies. Propagation measurements have also been made using the Canada/NASA CTS, and are included in the experimental programs of the Japanese BS, CS and ECS, the European L-Sat, the Italian Italsat, and the NASA ACTS. These satellites cover the allocated frequency bands at 11-12, 14, 18-20, and 28-30 GHz. Italsat will also have beacons at 40 and 50 GHz, to begin experiments in those frequency bands.

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TR-0084A(5417-03)-1	1 October 1984	UNCLASSIFIED

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